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BULLETIN NO. 51

STREET LIGHTING

no. 51

BY

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AND

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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UNIVERSITY OF ILLINOIS

ENGINEERING EXPERIMENT STATION

BULLETIN No. 51 DECEMBER 1911

STREET LIGHTING

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STREET LIGHTING

I. Introduction

1. *Preliminary.*—It is the purpose of this bulletin to make available information concerning street illumination. The suggestion which led to this compilation came from the many inquiries received by the Electrical Engineering Department each year from those interested in framing ordinances permitting corporations or individuals to operate street lighting systems. An attempt has been made to present this information in such a form as to be readily understood by the general public, without requiring any special technical knowledge. The data have been compiled from reliable sources, and checked in many instances by tests conducted by the writers.

This bulletin is designed to be of assistance to central station superintendents, and to the general public in selecting the proper lamp and fixing the charge for the same. It is also designed to be of value to the illuminating engineer and to the manufacturer, and in clearing up, or perhaps in preventing misunderstandings, which so frequently arise between municipalities and power companies. These misunderstandings, being usually the outcome of imperfect knowledge of the effectiveness and limitations of ordinary street lighting units, may readily be prevented if specifications and contracts be made definite and clear.

Many contracts are based upon the rates charged in cities of about the same size for the same class of service, regardless of the comparative operating cost of the installation in each case. Many companies do not compute the cost of any one particular branch of their service, but are satisfied if their total yearly balance shows a profit. Other companies, while knowing the cost of operation of the street lights, are still governed by the prevailing rate in similar cities. Thus it is that some companies may furnish the light to the city streets at an actual loss, but are compensated for this loss by special privileges in other branches of the service. It is believed by the writers that fewer misunderstandings would arise between the consumer and the company if each branch of service received its proper compensation.

This bulletin is also designed to show that the same type of light will not serve equally well for the illumination of all classes of city streets; and that certain accepted standard spacings of lights can never produce adequate and economical street illumination.

II. Production of Light

2. *General Theory.*—Probably the most familiar form of illuminant is the flame. At least, this is the earliest historical form. In the flame, the light is produced by small particles of carbon being brought to a temperature at which they will unite with the oxygen of the air. The heat which gives to these particles their incandescence comes from the union of the various compounds in the combustible with the oxygen. If the flame is cooled in any manner, the carbon will deposit in the form of soot before it reaches a sufficient temperature to burn. If enough air be mixed with the gas formed by the heated illuminant to consume the compounds, an almost non-luminous flame results. Thus the alcohol flame is nearly non-luminous; as is also that of the oxyhydrogen flame and the Bunsen burner. It is well-known that non-luminous flames may be made luminous by the introduction of some foreign substance which need not necessarily be consumed; of such character is the Welsbach burner.

In the Welsbach burner, another interesting phenomenon takes place. If the substance being heated is of a certain character, which is represented by carbon, a combination of colors is obtained for a given temperature. This is known as white light. If, however, the substance be some one of the metals, certain of the colors will be more pronounced; i. e., not all substances give off the same color when heated to the same temperature in a flame. This phenomenon is known as selective radiation. Use is made of this in the newer forms of illuminants in producing more light for a given amount of power or of illuminant. In the Welsbach burner, thoria and seria are spread upon a thin web of heat resisting material. These compounds, when heated to the high temperature of the gas flame, give off a much greater amount of light than would be given by carbon at the same temperature. Many other metals display this property to a greater or less extent. In this field, lie the recent advances in the development of arc lights.

3. *The Incandescent Lamp.*—In the incandescent lamp, light is produced by a fine filament or wire of some material, heated to

incandescence by a current of electricity. Formerly, all such lamps were made with filaments of carbon. These were followed by metallized filaments, and later by tantalum and tungsten, the latter being now used in the form of a drawn wire. All of these lights have their filaments in a vacuum to prevent rapid oxidation of the material, and also to prevent the heat from being conducted away from the filament as rapidly as it would be in air or any dense gas. Such lamps are made for house lighting and street lighting. *

4. *The Arc Lamp.*—(*a*) If two pieces of conducting material be connected in an electrical circuit with their ends touching, and these ends be separated slowly, a spark will be seen between them. If the voltage of the circuit be sufficient, portions of the terminals will be burned away, forming a vapor between them. This vapor is in itself a conductor, and current will continue to flow, even though the terminals are rather widely separated. Light will also be given off from the electrodes and the arc stream, thus giving the arc light.

In the earlier forms of arc lamp, plain carbon rods were commonly used for the terminals, or electrodes, as they are called. The voltage to be used across a given lamp, and the current necessary, are so determined for each type as to produce the proper characteristics. The old direct current open arc lamp required about 50 volts and took 9.6 amperes. This lamp was known as the "full arc" or 2000 "nominal candle-power" lamp. "A half arc" lamp using 6.6 amperes, known as the 1200 "nominal candle-power" lamp, was also used to a considerable extent. In any given type of lamp, the amount of light and the consumption of the carbons depend upon the current used and the size of the carbons. The light given off by an arc light proceeds partly from the electrodes and partly from the vapor or arc stream.

(*b*) In the direct current open arc, most of the light comes from a crater formed in the positive electrode. The upper electrode is made positive to throw most of the light in a downward direction, i. e., in the lower hemisphere. Only about five per cent of the light comes from the arc stream. The voltage across such a lamp must be increased when the arc is lengthened, but not directly in proportion to the distance between the electrodes. This is due to the fact that nearly a constant value of electromotive-force is consumed in vaporizing the electrode material.

*Tests on multiple burning lamps of different classes have been made by the Electrical Engineering Department, and reported in Engineering Experiment Station Bulletins No. 19 and 33.

Since any energy used in the arc stream produces but little light and lowers the efficiency, it is desirable to use as short an arc as possible without cutting off too much of the light. A long arc is also more difficult to maintain steady on account of the influence of air currents. The electrodes in such an arc are consumed rapidly; the positive being consumed about twice as fast as the negative. From 1.5 to 2.0 in. of positive electrode are consumed each hour. Such a lamp must be trimmed each day, i. e., the electrodes must be replaced, entailing expense in labor and material.

(*c*) The rapidity of the consumption of the electrodes in an open arc is due to their oxidation in the air. In order to lengthen the life, or number of hours of burning, of the electrodes, and decrease the expense due to trimming, the enclosed arc lamp was invented. In such a lamp, the arc is produced as in the open arc between carbon electrodes. It is, however, enclosed in a nearly air-tight chamber of glassware known as the inner globe, to distinguish it from the much larger outer globe used on nearly all arc lamps. The air being excluded the electrodes are consumed slowly, their life averaging about 100 hrs., or about 10 times that of the open arc. However, more expensive electrodes must be used, since they must fit quite closely into a gas cap at the top of the inner globe, and yet be fed by the mechanism with perfect freedom. Forced carbons are used in enclosed arcs and moulded carbons in open arcs. Enough air must be introduced into the inner globe of such a lamp to consume all the carbon volatilized by the arc, in order that it shall not deposit on the interior of the inner globe and shut in the light, lowering the efficiency of the lamp.

(*d*) Later improvements in the production of light from an arc lamp consist in securing more light from the arc stream. This has been accomplished by impregnating the electrodes with some metallic salt. The light from an arc stream of pure carbon is purplish in color, but since it comprises such a small proportion of the total light from the lamp, its effect is scarcely noticeable except when colors are being matched. Salts of certain metals, such as calcium, strontium, barium, titanium, sodium, etc., give their own characteristic color to the light, raising its efficiency by luminescence. These salts tend to make the arc unsteady or flickering, necessitating the introduction of other compounds to steady the light. Arc lamps using impregnated electrodes are known as flame arcs. When magnetite is used for

one of the electrodes, the lamp is called a magnetite or luminous arc, the latter being a trade name. Magnetite, containing iron, furnishes the conducting material in the arc stream. Most of the light is produced by a compound containing titanium, which is mixed with the magnetite. The electrode consists of a thin iron tube into which ground magnetite, titanium oxide, and chromite are packed. The magnetite melts, volatilizes, and carries with it the titanium. The chromite is used to absorb the fluid magnetite and steady the arc.

The electrodes in a flame arc lamp are consumed very rapidly. Even with long electrodes (14 to 18 in.), they do not last more than one night, or about 10 to 17 hours. The magnetite electrode, on the other hand, lasts from 85 to 200 hours, depending upon the current used. Since the electrodes contain considerable quantities of foreign impregnating materials which are not consumed in the arc, it is impossible to apply an ordinary inner globe to such a lamp. In fact, a draft tube or chimney is usually employed to carry away the products so that they are not deposited on the outer globe. It is obvious that such an opaque deposit would shut in most of the light after the lamp had operated a short time.

In the long burning flame arc, an attempt has been made to partially enclose the arc. Such a lamp has a fairly close-fitting inner globe and a condensing chamber. The gases pass first from the arc to the cool condensing chamber, where they deposit the foreign material. They return along the sides of the inner globe by natural draft. Otherwise the operation is similar to that of the enclosed arc lamps. The electrodes have a life of about 70 hours with ordinary current densities.

III. Systems of Distribution

5. *Series.*—There are two systems of electrical distribution, series and multiple. The series system is almost universal for street lighting. Either direct or alternating current may be used on either of these systems. Certain types of arc lamps will operate on either direct or alternating current, others on direct current only. In the direct current system, the current always flows in the same direction, i. e., from the positive terminal of the generator through the external circuit, and back to the negative terminal of the generator. In the alternating current system, the direction of flow of current changes very rapidly, and the electrodes of a lamp must change in polarity at the same time as

that of the circuit. In a 60-cycle alternating current circuit, the polarity changes 120 times per second. It is obvious that the current must be zero at some instant during the change. Hence the conducting path must have a low enough resistance to allow the current to pass again easily. In order to produce sufficient conducting material for an alternating current arc, one or both of the electrodes is made hollow, and filled with a softer and more volatile substance in the form of a continuous core. These electrodes are slightly more expansive than those used in the direct current lamps.

For street lighting, lamps are usually operated in series, i. e., the same current passes from the station through all the lamps in one group or circuit and back to the station. Apparatus is provided at the station to keep the current constant for each circuit of lamps. The mechanism of the lamp regulates the arc length and holds the voltage across the arc constant. This mechanism must also be able to start the lamp at any time, or to cut it out of service without breaking the circuit, if, for any reason, the lamp is inoperative, as any break in the circuit will cut out all the lamps of that circuit.

6. *Multiple.*—The first machines for supplying electrical energy from central stations were for the production of direct current. These machines were nearly always made to supply power to incandescent lamps at a low potential, about 100 volts. They were unsuitable for operating more than two arc lamps in series. Accordingly, direct current arc light generators were devised. Many of the early types are still in use with very little change from the first design. When only direct current is available from a station, it is necessary to provide a separate machine for the arc lights, since there is no means of changing low voltage direct current to a higher voltage. These machines can not be used to assist the low voltage machines in times of emergency. They thus form an additional investment and source of expense to the station for repairs.

Upon the introduction of alternating current generators and systems of distribution, direct current was driven out of the field where power must be transmitted for any considerable distance, on account of the fact that alternating currents may be transformed from one voltage to another readily and with very little loss. With low voltage distribution, a large investment, and consequent high fixed charge is required, due to the heavy copper conductors necessary for efficient transmission. Since the

greater part of the load on most central stations is due to incandescent lamps operated on multiple circuits, it was found desirable to install apparatus of constant voltage for their supply. Alternating current arc lamps were readily devised, and the direct current arc light generators were replaced by regulators or by constant current transformers, thus reducing the cost of station equipment.

Alternating current arc lamps are not as efficient light producers as direct current arc lamps, but the combination of alternating current arc lamps and regulators is more desirable than separate direct current arc light machines. Recently, rectifiers have been invented to convert constant alternating current into constant direct current, so that nearly any type of lamp may be operated with fair efficiency and continuity of service from an alternating current constant potential generator. This has led to increased activity in the perfection of direct current arc lamps for street lighting. Thus, to operate constant alternating current arc lamps from a central station supplying constant potential alternating current for multiple incandescent lighting, there will be required additional equipment of arc light transformers or regulators. To operate direct current arc lamps from such a station requires the same equipment as for alternating current lamps and the addition of a rectifier outfit for each group of lamps; or separate direct current arc light generators must be installed. Series incandescent lamps may be operated on either of these circuits.

A standard voltage of 110 volts has been adopted for use on multiple lighting circuits. Since arc lamps by their characteristics require considerably less voltage, some device must be used in series with the arc on multiple arc lamps to limit the current to the proper value. Any such device entails a considerable loss. In D. C. lamps, this loss is proportional to the differences between the line and arc voltage, multiplied by the current flowing. When the line voltage is a little greater than twice the arc voltage two arcs may be operated in series. This method is not satisfactory, since if one arc goes out, it extinguishes the other in series with it, or some complicated mechanism must introduce a resistance capable of absorbing the same voltage as one arc lamp.

In an A. C. system, a device known as a reactance coil may be used to reduce the voltage, at the same time absorbing only a nominal amount of power, not over 10% of the lamp watts. Such a device, however, introduces other undesirable factors into the circuit.

The reason for using series instead of multiple lights, is partly due to the less efficient lamps, and partly to the larger and much more expensive conductors required for the multiple system. The current for each group of lamps may be carried over a rather small size of conductor, without regard to the number of lamps in circuit, if they are all connected in series. A No. 8 B & S gauge wire would be of sufficient current carrying capacity. Some companies, however, use No. 6 or No. 4 on account of the greater mechanical strength when open wiring is used. If the same number of lamps were fed over a multiple circuit, several times the amount of money would have to be invested in copper, making a more expensive and less efficient installation.

IV. Photometry and Illumination

7. *Photometry.*—The accurate photometric measurement of the intensity of light from an arc lamp is very difficult to make even with the facilities of the best laboratories. This is due to the unsteadiness of the light. Devices have been made for determining the mean spherical intensity of such lights at one setting. These devices are, however, very expensive, and are beyond the means of most central station laboratories. The distribution curves, as published by many different writers, are usually quite reliable. They are sufficiently accurate for calculating street illumination. Such curves are illustrated in the following pages.

It must be remembered in these comparisons that most curves are taken in a laboratory where the lamp is kept in proper adjustment throughout the test, and the glassware carefully cleaned. The actual illumination received from such lights, when in continuous service, and with ordinary care in trimming, does not average over 80 per cent of the laboratory values. This loss of light is due to dirt on the glassware, deposit on the inner globe of enclosed lamps, and lack of adjustment of the mechanism due to wear, corrosion, etc. On the whole, illumination readings of actual installations are much more reliable, if made with sufficient care.

8. *The X Value.*—There is great need of a new standardization of the method of specifying street illumination in this country. In 1907, the National Electric Lamp Association adopted a standard specification for street lights. Comparative tests of the illumination thrown upon the street, at distances of between 200 and 300 ft. from the arc, were made upon the various street lights

then in use. From these values, a factor known as the "X" value of the lamp was computed. The X value shows the relation between the illumination from the lamp in question, and that given by a standard 16 candle power incandescent lamp at 1/X of the distance. Thus, for example, an arc lamp, having an X value of 4, gives the same illumination as a 16 candle power incandescent lamp at ¼ the distance, and a lamp having an X value of 5 gives the same illumination as the 16 candle power incandescent lamp at ⅕ the distance. Thus a lamp which has an X value of 5, at a distance of 250 ft., gives the same illumination as a 16 candle power incandescent lamp, at a distance of 50 ft. With the advent of the demand for brighter illumination in this country, necessitating closer spacing of the lamps, this specification is no longer a measure of the value of the lamp. Other methods of specification used in different countries, or by different engineers, include horizontal illumination on a plane about four feet above the street surface, illumination on a vertical plane at a given point, and illumination on a plane normal to the rays of light from the lamp and at various distances.

As will be shown later, the illumination on the street surface depends not only upon the light at a certain angle, but upon the distribution of light about the arc at all angles, and upon the height and spacing of the lamps. The specification of the illumination should also include the distribution of light about the lamp for a given condition. The amount and character of the illumination required depends upon the character of the street surface and the use made of the street. Thus a lamp with a good X value may be suitable for lighting one street, but wholly unsuitable for another.

9. *Measurement of Illumination.*—Since the light from any one arc lamp varies continuously on account of the arc shifting about on the ends of the electrodes, it is difficult to arrive at accurate results in the measurement of street illumination. In thoroughfares where several arcs per pole or incandescent lamps are used, the illumination is much more steady. The illumination may be measured by some form of illuminometer. Where accurate results are not necessary, some form of reading photometer may be used. Such an instrument is shown in section in Fig. 1. The observer stands with his back toward the light, and looks into the photometer through the aperture A, his eyes being shielded from other lights. The illumination to be measured is that upon the surface C, which is a card containing lines of letters

or characters of varying boldness. Such a card is illustrated in Fig. 2. The light which falls on the surface C comes into the

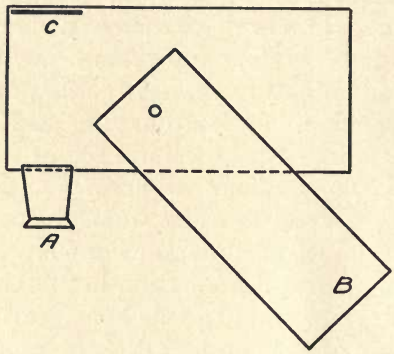

FIG. 1. SECTION OF A READING PHOTOMETER

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FIG. 2. SAMPLE CARD FOR READING PHOTOMETER

photometer through the tube B. The line of type on the card is so selected as to show the small characters dimly or blurred, while the large characters and capitals remain clear-cut. The distance from the observer to the light is also measured.

By previously calibrating the instrument by comparison with a standard lamp, values of illumination may be determined with an accuracy of from 5 to 10 per cent, depending upon the intensity of the illumination to be measured. Calibration is performed by finding the distance from the standard light at which the different lines of characters may be read. The illumination in foot candles may be computed from the candle power of the lamp and from the distance in feet as follows. Suppose the lamp giving 16 candle power to be in a horizontal position, and suppose the distance from the lamp to be 4 ft. Then since the illumination, from a small object as a source, varies inversely as the square of the distance, the illumination would be $\frac{16}{4^2} = 1$, or one foot candle. This instrument measures the illumination on a normal plane. To reduce the illumination to that on a horizontal plane, these values must be multiplied by the cosine of the angle between this plane and the street surface at that point. This form of illuminometer is inexpensive and may be constructed in any carpenter shop. Other more expensive illuminometers are on the market which are more accurate, but are also more difficult to operate. Unless there is considerable reflection from buildings, the street illumination may be calculated quite approximately from the light distribution curve of the lamp, its height and the distance from its base to the point considered, as will be explained later.

10. *Distribution Curves.*—On the following pages will be found the distribution curves of the more common lamps used for street lighting. Data for the distribution curves are obtained by measuring the candle power at different angles in a vertical plane about the lamp by means of a photometer. In such a device, the lamp to be measured is compared with a standard lamp. This comparison is difficult to make for an arc lamp on account of the high intensity of the light in some directions, and the continual shifting about of the arc on the electrodes, with the consequent change in the distribution. The color of the light, in some instances differing from that of the comparison lamp, makes the determination more difficult. Special and expensive apparatus must also be used for obtaining the intensity at different angles. The results of such determinations are shown in Fig. 3, 4, 5 and 6. A complete circle is divided into 360°, and radii are drawn at convenient angles. On these radii, the intensity in candle power is laid off at convenient scale. The points thus determined are connected by a smooth curve known as the "distribution curve". The candle power in any direction in a vertical circle is the length of the

radius, at that angle, intercepted by the curve, multiplied by the candle power scale. The distribution in a horizontal plane through the source is usually a circle; so that the distribution in one vertical plane represents the lamp distribution with sufficient accuracy.

Since, in street lighting, only the light thrown downward, i. e., in the lower hemisphere, is useful for illumination, only that portion of the curve is shown. All light in the upper hemisphere is wasted unless a reflector is used to divert these beams into useful directions. In order to save space and allow a larger scale, only one-half the lower hemisphere is shown in this bulletin, the other being exactly like it.

In Fig. 3, A is the distribution curve from a 9.6 amperes, direct current open arc lamp. It will be seen that the maximum

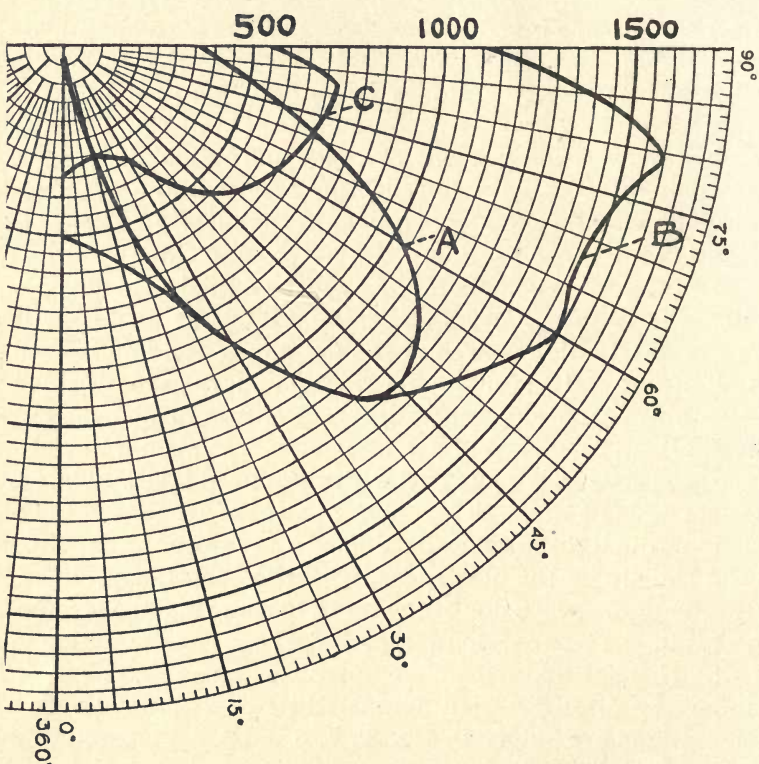

FIG. 3. DISTRIBUTION CURVES OF ARC LAMPS WITH CLEAR OUTER GLOBES

A. 9.6 Amperes, D. C. Open Arc.
B. 6.6 Amperes, D. C. Magnetite Arc.
C. 4 Amperes, D. C. Magnetite Arc.

intensity is at 45° from the vertical axis. The ray in this direction will strike the ground at a distance equal to the height of the lamp above the street surface. The light from this lamp comes mostly from the crater in the upper or positive electrode. The arc being short, the shadow cast by the lower electrode will cover a considerable angle, as seen in Fig. 7. The source of light being a small area, its intrinsic brilliancy, or candle power per sq. in., is of necessity very high. Shadows from the side rods and lower carbon of the lamp are also more or less annoying, because they are so much magnified on the surface of the ground.

In the enclosed direct current arc lamp, the curve for which is shown in Fig. 4 as C, the same shadow from the lower electrode appears, but it is not so intense on account of the fact that the curve is modified by the presence of the inner globe; the arc also

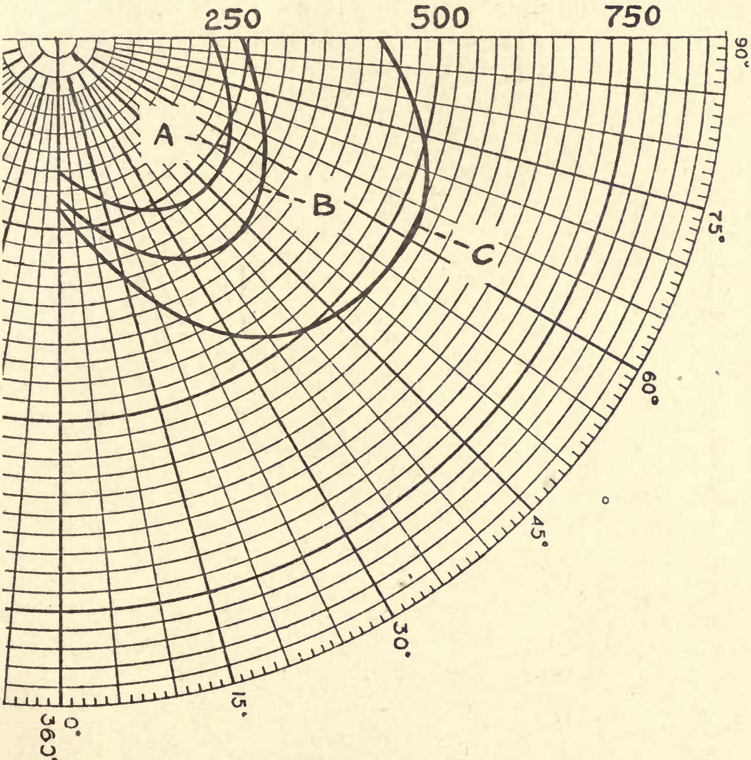

Fig. 4. Distribution Curves of Arc Lamps

A. 6.6 Amperes A C. Enclosed, Opal Inner. Clear Outer Globe.
B. 7.5 Amperes A. C. Enclosed, Opal Inner, Clear Outer Globe.
C. 6.6 Amperes D. C. Enclosed. Opal Inner, Clear Outer Globe.

is longer. The globe absorbs some of the light, and also becomes a secondary source of light, making the intensity less in the maximum direction and greater in other directions and at wider angles.

In the alternating current enclosed arc lamp, as much light is thrown in the upper hemisphere as in the lower, since craters are formed alternately in the upper and the lower electrodes. A reflector or shade should be used always with such a lamp, to return as much of the light as possible to the lower hemisphere. Two curves for such lamps are shown as A and B in Fig. 4, A being for a 6.6 amperes lamp, and B for a 7.5 amperes lamp.

In the flame arc lamp, the distribution curve depends upon whether the arc is formed between vertical electrodes, as shown in Fig. 8, or between inclined electrodes as shown in Fig. 9. In the latter case, the light will all be in a downward direction and strongest immediately below the light, as in B, Fig. 5. When

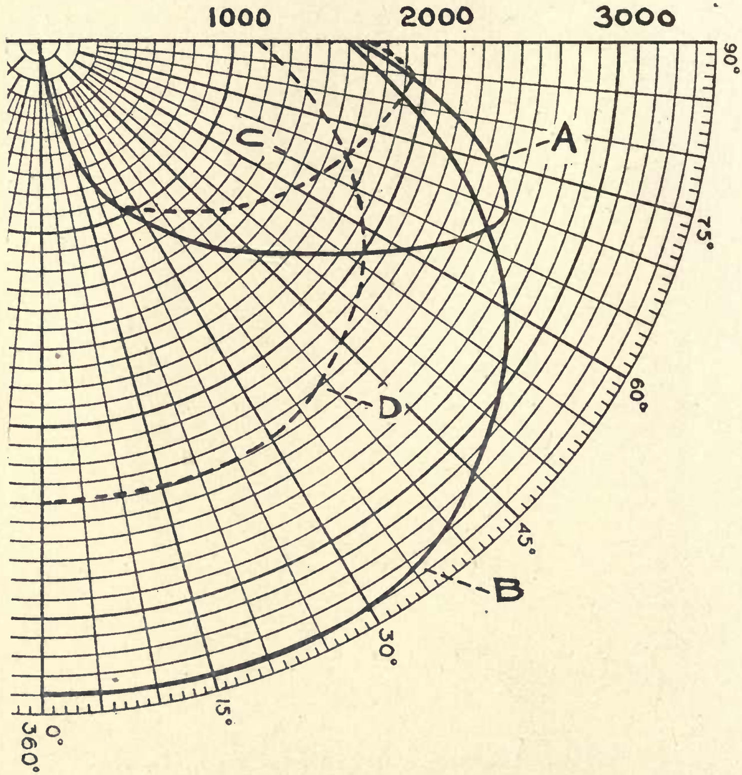

FIG. 5. DISTRIBUTION CURVES OF ARC LAMPS

A. Long Burning Flame, 5.5 Amperes, D. C., Clear Inner and Clear Outer Globe.
B. Inclined Electrode Short Burning Flame, 10 Amperes D. C., Clear Outer Globe.
C. Long Burning Flame, 5.5 Amperes, D. C., Clear Inner, Opal Outer Globe.

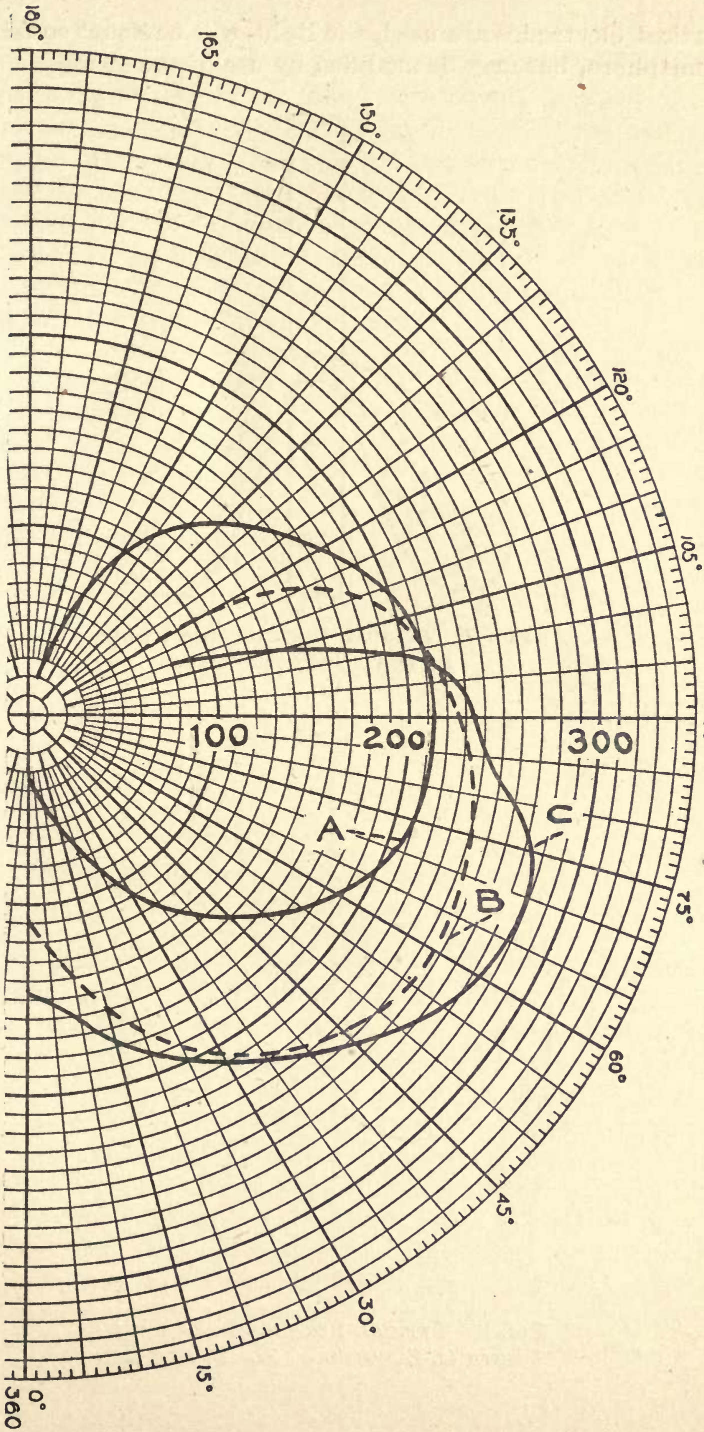

FIG. 6. DISTRIBUTION CURVE FOR 200–CANDLE POWER SERIES TUNGSTEN LAMP

A. Bare Lamp.
B. Lamp with 22 inch Enamelled Reflector.
C. Same with Radial Wave Reflector.

vertical electrodes are used, the light will be about equal in each hemisphere, but may be modified by use of the shade.

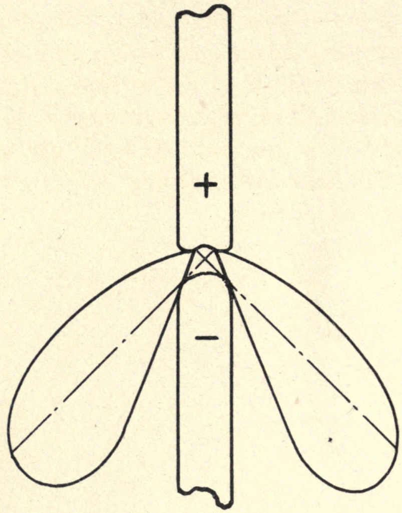

FIG. 7. TYPICAL DISTRIBUTION CURVE OF D. C. OPEN ARC LAMP

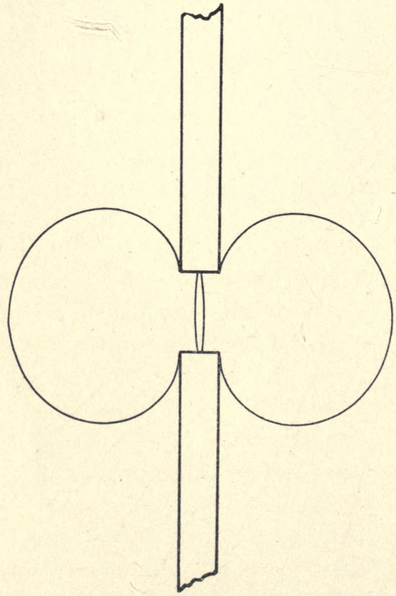

FIG. 8. TYPICAL DISTRIBUTION CURVE OF VERTICAL ELECTRODE, FLAME ARC LAMP

The distribution curve for a tungsten series incandescent light is similar in shape to that shown in Fig. 8, or in A, Fig. 6, which is the distribution curve for a rated 200 candle-power lamp. Various shades and reflectors have been developed for use with these lamps. They vary from a 22-in. enamel reflector, giving a distribution as shown in B, Fig. 6, or the radial reflector with its curve C, Fig. 6, and various unsymmetrical reflectors throwing most of the light into the middle of the street and very little on the sidewalk. For this latter shade, the light must be supported at the side of the street.

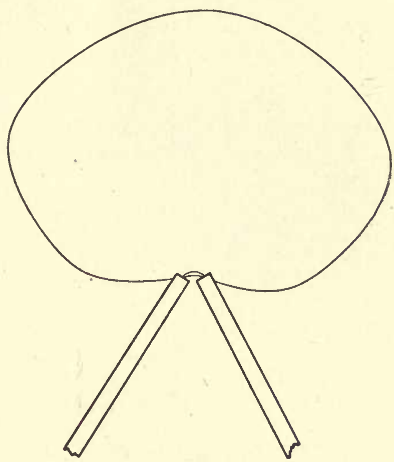

FIG. 9. TYPICAL DISTRIBUTION CURVE, INCLINED ELECTRODE, FLAME ARC LAMP

11. *Effect of Shades and Reflectors.*—That the distribution curves of lamps may be greatly altered by the use of reflectors and globes has already been mentioned. To illustrate the effect of a reflector, two curves of the same lamp are shown in Fig. 10. Curve A is a distribution curve for a long burning flame arc lamp with clear inner globe and thin opal outer globe but with no reflector. Curve B is for the same lamp, with the same globes and with a 24-in. white porcelain enameled reflector added. The shape of the distribution curve has thus been altered to suit a certain condition. The mean lower hemispherical candle-power has been increased by about 5 per cent, but the mean spherical candle-power has been decreased by 24 per cent. In arc lamps using stationary lower electrodes, the shape of the distribution

curve, with reflector, changes during the life of the electrodes, due to the change of position of the source of light. Fig. 11 illustrates the effect of globes on the distribution curve of the

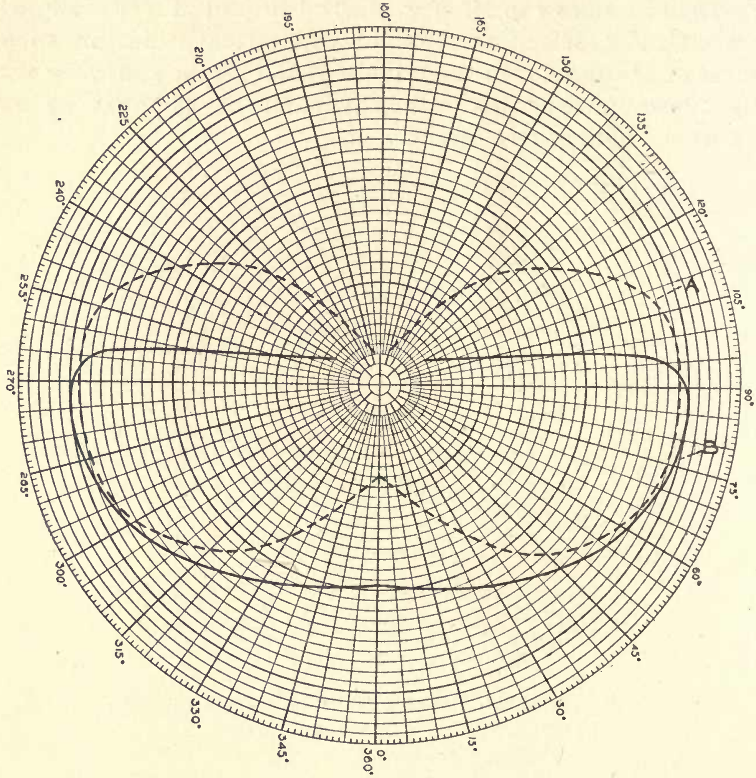

FIG. 10

A. Distribution Curve of the Long Burning Flame Arc Lamp with Opal Globe, No Reflector.
B. Same Lamp with Reflector.

lamp. Curve A is for a vertical carbon flame arc lamp with 26 in. reflector and with clear outer globe. Curves B and C are for the same lamp, with the same reflector, but with opal globes of different densities. Nearly the same shape of distribution curve has been obtained by both of the globes. However, 10 per cent of the light has been absorbed by one of the globes and 25 per cent by the other. Thus it is seen that an opal globe tends to make the distribution curve more uniform, but in so doing, it

absorbs a considerable portion of the light. This type of globe also lowers the intrinsic brilliancy, since it becomes, in effect, the source of light.

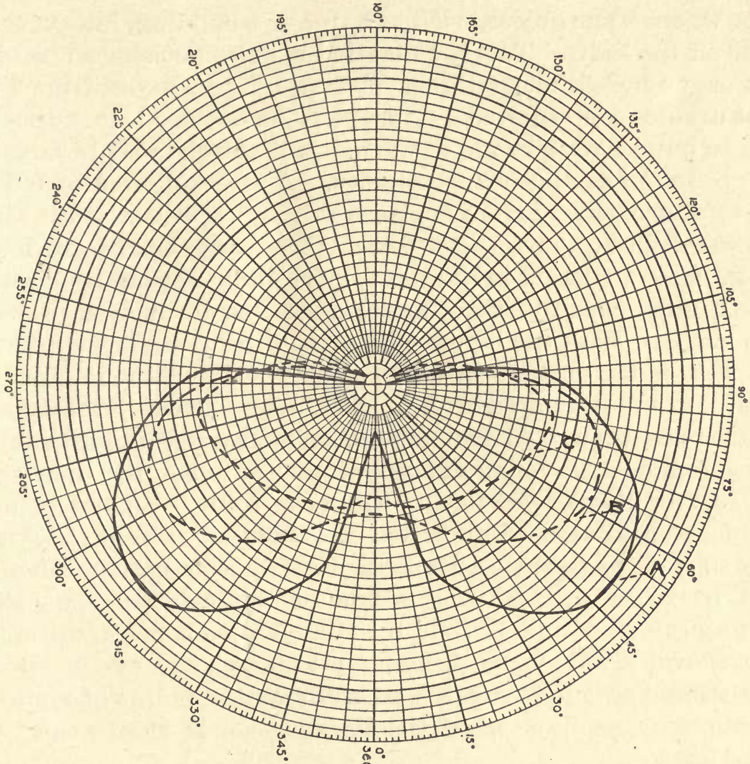

FIG. 11. EFFECT OF GLOBE

A. Vertical Electrode, Flame Arc Lamp with Reflector and Clear Outer Globe.
B. Same Lamp with Alba Globe.
C. Same Lamp with Dense Opal Globe.

V. CALCULATION OF ILLUMINATION

12 *General Theory.*—In order to obtain the best results from general illumination, it should be as nearly uniform as possible over the whole surface. The object of street illumination is to make the street safer for travel after nightfall. To accomplish this result, the eye must be able to distinguish objects with sufficient clearness and at a fair distance, so that they may be avoided if necessary. With the advent of the automobile and other swiftly moving vehicles, the distinctness with which objects may be seen must be improved, so that danger may easily be avoided.

The illumination produced by full moon has a maximum of about .02 foot candle. The eye has become accustomed to distinguish objects fairly well by this illumination, even at a considerable distance. Moreover, this illumination is uniform except where some object, such as a tree or a building, intervenes to shut off the light. This illumination is not sufficient for reading ordinary type without fatigue. For reading purposes from 1 to 3 foot candles are required. The eye is accustomed to adjust itself to quite a wide range of intensity, if the changes in intensity do not follow each other too rapidly. A street lighted by 6.6 amperes alternating current enclosed arc lights placed at the street crossings 25 ft. above the street surface where blocks are 400 ft. long, has a variation in its horizontal illumination of from .28 foot candle, near the lamp, to .0014 foot candle midway between the lamps. With the lamps placed at alternate street intersections, as is the custom in smaller cities, the minimum illumination, i. e. the illumination near the other street intersections, will be less than .0001 foot candle, an almost negligible quantity. An automobile traveling at a speed of 25 miles per hour along a street lighted every 400 ft. will pass from the point of minimum to maximum illumination in about 5.5 seconds. During this time, the eye must accustom itself to a range in illumination of 200 to 1, producing fatigue in the eye and uncertainty in discerning objects. When the illumination is not uniform, but varies over a wide range from lamp to lamp, the eye is not able to distinguish objects nearly so well, at the points of minimum illumination, as it is when the illumination is more nearly uniform but low.

The intrinsic brilliancy of the light source in the line of vision is another consideration in selecting the proper lamps, as well as their height and spacing. The pupil of the eye adjusts itself so as to admit a certain quantity of light. A source of light of high intrinsic brilliancy, in the line of vision, closes the pupil of the eye so that insufficient light is admitted to distinguish dimly lighted objects clearly. This effect is made apparent, in ordinary street lighting, by the fact that a person facing an arc light is unable to see objects beyond the light until he is so near the light that it is no longer in his line of vision. The effect is not so apparent in brightly lighted streets where the illumination is also more uniform.

13. *Tables and Curves.*—(*a*) In order to calculate the illumination on the street surface, the following equations have been

derived. Fig. 12 represents a light, L, suspended at a height, h, above the center of the street, BC. The intensity of the light in the direction, LB, at an angle ϕ with the vertical may be

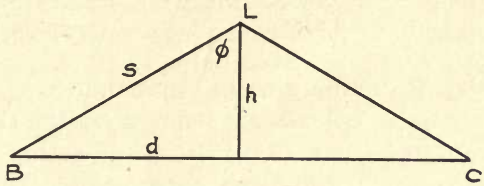

FIG. 12

obtained from the distribution curve of the lamp. Let this intensity of the light source be I. Then the intensity of the illumination at B, on a plane perpendicular to the ray of light, would be

$$i = \frac{I}{s^2} \quad \text{(1)}$$

The illumination on the horizontal surface of the street would be

$$i_h = \frac{I \cos \phi}{s^2} \quad \text{(2)}$$

since the ray is at the angle ϕ with the vertical. Taking the point B, at a horizontal distance d, from the lamp

$$\tan \phi = d/h \quad \text{(3)}$$

and

$$s = h/\cos \phi \quad \text{(4)}$$

Hence the normal illumination, or the illumination on a plane perpendicular to the ray of light would be

$$i = \frac{I \cos^2 \phi}{h^2} \quad \text{(5)}$$

and on the street surface

$$i = \frac{I \cos^3 \phi}{h^2} \quad \text{(6)}$$

In order to have uniform normal illumination, the intensity in any direction about the lamp must vary according to the equation

$$I = \frac{i\, h^2}{\cos^2 \phi} \quad \text{(7)}$$

derived from equation (5) or

$$I = \frac{i\, h^2}{\cos^3 \phi} \quad \text{(8)}$$

from equation (6), for uniform horizontal distribution. In these two equations,

if

h = height of lamp in feet above the street;

and

I = intensity of the light in candle power at the angle ϕ from the vertical;

then

i = intensity of illumination in foot candles.

Table 1 has been calculated from equation (7) for different values of h, ranging from 15 to 50 ft. In the same manner, Table 2 has been calculated from equation (8). In each table, a uniform intensity of illumination of .01 foot candle has been assumed. For any other intensity, these values should be

TABLE 1

Candle Power at Lamp for .01 Foot Candle Normal Illumination on Street.

ϕ	$\cos\phi$	$\frac{1}{\cos^2\phi}$	Height of lamp—feet					
			15	20	25	30	40	50
0	1.000	1	2.25	4.00	6.25	9.00	16.00	25.00
5	.996	1.01	2.27	4.04	6.31	9.09	16.16	25.25
10	.985	1.03	2.32	4.12	6.44	9.27	16.48	25.75
15	.966	1.07	2.41	4.28	6.69	9.63	17.12	26.75
20	.940	1.13	2.57	4.56	7.13	10.17	18.26	28.50
25	.906	1.22	2.75	4.88	7.63	10.98	19.52	30.50
30	.866	1.33	2.99	5.32	8.31	11.97	21.30	33.30
35	.819	1.49	3.35	5.96	9.32	13.41	23.80	37.3
40	.766	1.70	3.83	6.80	10.60	15.3	27.2	42.5
45	.707	2.00	4.50	8.00	12.50	18.0	32.0	50.0
50	.643	2.43	5.47	9.72	15.16	21.8	38.9	60.8
55	.547	3.03	6.33	12.12	18.93	27.3	48.5	76.0
60	.500	4.00	9.00	16.0	25.0	36.0	64.0	100.0
65	.423	5.59	12.68	22.4	35.0	50.3	89.7	140.0
67.5	.383	6.82	15.35	27.3	42.6	61.4	109	170.5
70	.342	8.35	18.8	33.4	52.5	75.1	133.5	209
72.5	.301	11.05	24.9	44.2	69.1	99.5	177	276
75	.259	14.90	34.0	60.4	94.4	136	242	378
76	.242	17.10	38.5	68.4	107.	154	274	428
77	.225	19.75	44.5	79.0	123	178	316	494
78	.208	23.10	52.0	92.4	145	209	370	577
79	.191	27.4	61.7	109.6	171	246	438	687
80	.1736	33.2	74.8	133.	208	299	532	832
81	.1564	40.8	92.2	163	255	367	653	1020
82	.1392	51.7	116.	207	323	465	830	1292
83	.1219	67.3	151	269	421	606	1077	1682
84	.1045	91.7	206	367	573	826	1467	2290
85	.0872	131.7	296	527	824	1180	2110	3290
85.5	.0785	162.5	366	650	1010	1460	2600	4060
86.	.0698	205	461	820	1300	1850	3280	5120
86.5	.0610	269	605	1070	1680	2420	4300	6730
87.	.0523	366	824	1460	2290	3300	5850	9150
87.25	.0480	434	980	1740	2710	3900	6960	10850
87.5	.0436	527	1185	2110	3300	4740	8450	13170
87.75	.03926	650	1460	2600	4060	5850	10400	16250
88.	.03490	822	1850	3290	5140	7400	13150	20550
88.25	.03054	1072	2300	4290	6700	9540	17150	26800
88.5	.02618	1460	3290	5840	9120	13100	23400	36500
89.	.01745	3290	7420	13100	20500	29600	52700	82400

multiplied by the ratio between .01 and the intensity chosen. Thus, for .10 foot candle, the values should be multiplied by 10.

TABLE 2

Candle Power at Lamp for .01 Foot Candle Horizontal Illumination at Street

ϕ	$\cos\phi$	$\frac{1}{\cos^3\phi}$	Height of Lamp					
			15′	20′	25′	30′	40′	50′
0	1.000	1.000	2.25	4.00	6.25	9.00	16.00	25.0
5	.996	1.015	2.28	4.06	6.35	9.14	16.25	25.4
10	.985	1.045	2.35	4.18	6.43	9.41	16.72	26.15
15	.966	1.11	2.50	4.44	6.94	9.99	17.76	27.75
20	.940	1.20	2.70	4.80	7.50	10.80	19.20	30.0
25	.906	1.35	3.04	5.00	8.44	12.15	21.60	33.7
30	.866	1.54	3.47	6.16	9.53	13.86	24.65	38.5
35	.819	1.82	4.09	7.28	11.35	16.4	29.1	45.5
40	.766	2.22	5.00	8.88	13.85	20.0	35.5	55.2
45	.707	2.83	6.37	11.30	17.68	25.4	45.3	70.8
50	.643	3.73	8.42	14.9	23.3	33.6	59.7	93.5
55	.547	5.27	11.85	21.1	32.9	47.4	84.5	131.7
60	.500	8.00	18.00	32.0	50.0	72.0	128.0	200
65	.423	13.20	29.7	53.8	82.5	119	211	330
67.5	.383	17.8	40.1	71.2	111	160	285	445
70	.342	24.4	54.9	97.6	152	220	390	610
72.5	.301	36.7	82.6	146	229	330	587	918
75	.259	58.3	131.2	233	364	525	935	1460
76	.242	70.5	159	282	440	635	1130	1760
77	.225	87.8	198	351	549	790	1410	2200
78	.208	111.2	250	445	695	1000	1780	2780
79	.191	143.3	323	574	896	1290	2290	3590
80	.1736	191.0	430	764	1190	1720	3060	4780
81	.1564	261.0	574	1040	1630	2350	4180	6530
82	.1392	371.0	835	1480	2320	3340	5940	9280
83	.1219	552.0	1242	2210	3450	4970	8850	13800
84	.1045	876.0	1970	3500	5480	7880	14000	21900
85	.0872	1510	3400	6040	9440	13600	24200	37800
85.5	.0785	2070	4660	8280	12900	13600	33100	51800
86	.0698	2930	6600	11720	18320	26380	46800	73400
86.5	.0610	4410	9950	17650	27600	39700	70600	110000
87	.0523	6970	15700	27900	43500	62700	111500	174200
87.25	.0480	9050	20400	36200	56600	81500	145000	226000
87.5	.0436	12100	27200	48400	75600	118000	194000	303000
87.75	.03926	16500	37100	66000	103000	148000	264000	413000
88	.03490	23500	52900	94000	146500	211000	376000	588000
88.25	.03054							
88.5	.02618							
89	.01745							

From equation (3), the value of ϕ has been calculated for different values of d and h over as wide a range as necessary for ordinary exterior illumination. These angles are given in Table 3. Factors have also been included in Table 3 to aid in the calculation of illumination. For each height and distance, two factors are given by which the intensities in thousands of candle power must be multiplied to give the illumination at the chosen point. The first line is for normal and the second for horizontal illumination, respectively. By referring to Tables 1

and 2, the difficulty will be seen of securing uniform low illumination over large areas with economical height and spacing of lamps. Higher values of intensity may be secured by placing the lamps sufficiently close so that the illumination from one assists that from the others, increasing the minimum illumination.

TABLE 3

TABLE OF ANGLES AND FACTORS FOR VARIOUS HEIGHTS AND DISTANCES

$$a = \frac{\cos^2 \phi}{h^2} \times 1000\text{—Normal illumination}$$

$$b = \frac{\cos^3 \phi}{h^2} \times 1000\text{—Horizontal illumination}$$

Distance feet	Height—feet					
	15	20	25	30	40	50
25	59°2′	51°20′	45°-0′	39°50′	31°-0′	26°-3′
a	1.18	.977	.800	.656	.458	.321
b	.607	.610	.566	.504	.393	.287
50	73°18′	68°12′	63°27′	59°2′	51°20′	45°0′
a	.366	.345	.323	.295	.244	.200
b	.105	.128	.143	.150	.152	.141
75	78°41′	75°4′	71°34′	68°12′	62°0′	56°20′
a	.171	.168	.161	.153	.138	.123
b	.0335	.043	.051	.057	.065	.0682
100	81°28′	78°41′	75°57′	73°20′	68°12′	63°26′
a	.100	.0987	.0915	.0956	.0863	.0804
b	.0148	.0193	.022	.027	.032	.036
125	83°10′	80°55′	78°41′	76°30′	72°20′	68°10′
a	.0662	.0625	.0615	.0607	.0577	.0553
b	.0079	.010	.012	.0141	.0125	.0205
150	84°17′	82°24′	80°32′	78°41′	75°4′	71°34′
a	.0452	.0436	.0433	.0427	.0416	.0400
b	.0045	.0058	.0071	.0084	.0107	.0126
200	85°42′	84°17′	82°52′	81°28′	78°41′	75°57′
a	.0254	.0252	.0247	.0245	.0234	.0233
b	.0019	.0025	.0031	.0036	.0046	.0056
250	86°34′	85°25′	84°17′	83°10′	80°55′	78°41′
a	.016	.016	.016	.0158	.0156	.0154
b	.00106	.00128	.0016	.0019	.00247	.0030
300	87°8′	86°11′	85°14′	84°17′	82°24′	80°32′
a	.0111	.0111	.0111	.011	.0109	.0108
b	.00055	.00173	.00091	.0011	.00144	.0018
350	87°33′	86°44′	85°50′	85°5′	83°29′	81°57′
a	.00812	.00812	.00812	.00812	.00807	.0077
b	.00035	.00046	.00058	.00070	.00091	.0011
400	87°51′	87°8′	86°25′	85°42′	84°17′	82°52′
a	.00625	.00625	.00625	.00625	.0061	.0060
b	.00023	.00031	.00039	.00047	.0006	.00074
450	88°5′	87°27′	86°49′	86°11′	84°55′	83°40′
a	.0050	.00494	.00492	.00491	.00490	.00487
b	.00017	.00022	.00027	.00032	.00043	.000536
500	88°17′	87°42′	87°8′	86°34′	85°25′	84°17′
a	.004	.004	.004	.004	.004	.004
b	.00012	.00016	.00020	.00024	.00032	.0004

This method is used in interior illumination, and in the brilliant illumination of streets. From Table 3 and the distribution curves of the several lamps, Tables 4 to 13 have been computed. These tables give the foot candles illumination on the normal and horizontal planes for different heights and spacing of the lamps.

TABLE 4

Normal and Horizontal Distribution at Street Surface for 9.6 Amperes D. C. Open Arc Lamp

Height feet	Distance—feet											
	0	25	50	75	100	125	150	200	250	300	350	400
15	.222	1.185	.242	.089	.0476	.030	.019	.0104	.0065	.0044	.0032	.0025
	.222	.610	.0693	.0174	.0070	.00355	.0019	.00078	.00043	.00028	.00014	.00009
20	.125	1.18	.228	.101	.050	.031	.021	.011	.0067	.0044	.0031	.0024
	.125	.735	.0845	.0258	.0098	.0049	.0028	.0011	.00054	.00029	.00017	.00012
25	.080	1.00	.294	.120	.057	.031	.022	.011	.0064	.0046	.0038	.0025
	.080	.700	.133	.0384	.0130	.0061	.0035	.0014	.00068	.00038	.00024	.00016
30	.0555	.788	.303	.116	.063	.036	.022	.012	.0068	.0046	.0034	.0026
	.0555	.605	.154	.0435	.018	.0083	.0043	.0018	.00082	.00046	.0003	.00019
40	.0312	.417	.296	.138	.069	.038	.025	.012	.0076	.0050	.0034	.0026
	.0312	.356	.185	.065	.026	.012	.0064	.0023	.0012	.00066	.00038	0 0025
50	.020	.284	.250	.140	.0735	.044	.028	.0137	.0079	.0052	.0037	.0026
	.020	.253	.176	.0775	.033	.0165	.0089	.0033	.0015	.00089	.00052	.00032

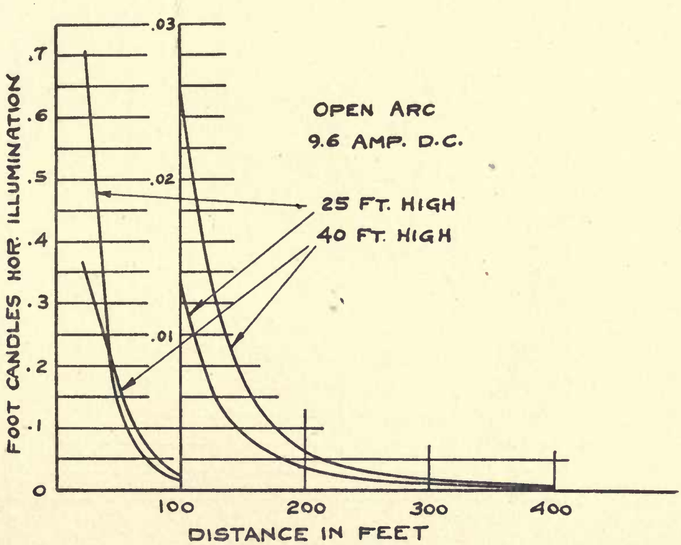

Fig. 13. Horizontal Distribution at Street Surface for 9.6 Amp. D. C. Open Arc Lamp

TABLE 5

NORMAL AND HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR 6.6 AMPERES D. C. MAGNETITE ARC LAMP

Height feet	Distance—feet											
	0	25	50	75	100	125	150	200	250	300	350	400
15	2.22	1.76	.550	.269	.155	.100	.0660	.0320	.0208	.0142	.0101	.0075
	2.22	.91	.169	.053	.023	.0118	.0066	.0024	.00138	.00070	.00044	.00028
20	1.25	1.30	.506	.456	.134	.0950	.0658	.0357	.0223	.0146	.0104	.0080
	1.25	.815	.188	.0656	.0267	.0153	.0088	.0035	.00178	.00096	.00059	.0004
25	.60	.985	.480	.242	.142	.0970	.0675	.0366	.0236	.0154	.0109	.0083
	.60	.696	.225	.0765	.0342	.0189	.0111	.0046	.0024	.0013	.00078	.00051
30	.556	.590	.437	.225	.143	.0937	.0635	.0387	.0235	.0160	.0114	.0085
	.556	.454	.223	.0840	.0405	.0218	.0125	.0056	.0028	.0016	.0010	.00064
40	.313	.435	.330	.203	.126	.0872	.0635	.0370	.0246	.0168	.0119	.0086
	.313	.373	.205	.0955	.0470	.0265	.0163	.00727	.0039	.0022	.00134	.00084
50	.200	.257	.246	.178	.117	.0813	.0595	.0356	.0243	.0171	.0116	.0090
	.200	.230	.173	.099	.052	.0301	.0188	.00856	.0047	.00286	.0017	.00111

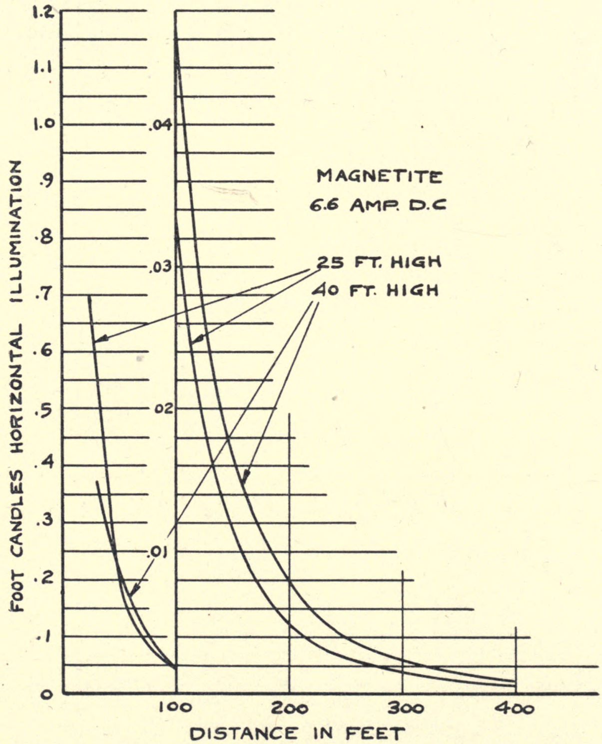

FIG. 14. HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR A 6.6 AMP. MAGNETITE ARC LAMP

TABLE 6

NORMAL AND HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR 4 AMPERES D. C. MAGNETITE ARC LAMP

Height feet	Distance—feet											
	0	25	50	75	100	125	150	200	250	300	350	400
15	1.55	.768	.259	.125	.0742	.0459	.0303	.0155	.01015	.0069	.0050	.00375
	1.55	.395	.0743	.0244	.0110	.00547	.00302	.00116	.00067	.00034	.00021	.00014
20	.875	.596	.237	.1210	.0713	.0454	.0305	.0162	.0107	.0071	.0050	.0039
	.875	.372	.0872	.0310	.0140	.00726	.00406	.00161	.00086	.00047	.00028	.00019
25	.560	.440	.213	.113	.066	.0448	.0311	.0163	.0110	.00743	.00540	.0040
	.560	.311	.095	.0357	.0159	.00875	.0051	.00217	.0011	.00061	.00037	.00025
30	.389	.328	.192	.098	.0677	.0438	.0311	.0167	.0110	.00765	.00543	.00445
	.389	.252	.0975	.0366	.0191	.0102	.00613	.0026	.0013	.00076	.00047	.0003
40	.219	.167	.148	.091	.0588	.0400	.0300	.0160	.0112	.0076	.0057	.0040
	.219	.143	.092	.0428	.0218	.0123	.0077	.00334	.00177	.0010	.00063	.0004
50	.140	.108	.110	.0718	.0537	.0380	.0278	.0158	.0112	.0079	.0055	.0042
	.140	.0965	.0777	.0398	.0241	.0141	.00875	.0040	.0022	.0013	.00078	.0005

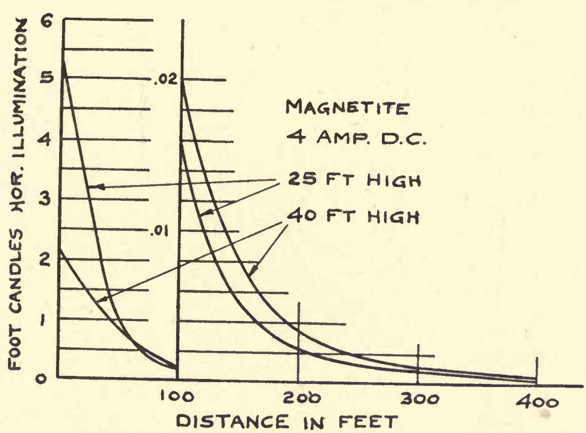

FIG. 15. HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR A 4.0 AMP. MAGNETITE ARC LAMP

TABLE 7

Normal and Horizontal Distribution at Street Surface for 6.6 Amperes D. C. Enclosed Arc Lamp

Height feet	Distance—feet											
	0	25	50	75	100	125	150	200	250	300	350	400
15	1.00	.62	.187	.083	.0475	.0310	.0183	.0113	.0075	.00485	.00355	.0027
	1.00	.32	.054	.012	.007	.0036	.0018	.00045	.00036	.00024	.00015	.0001
20	.563	.503	.180	.084	.05	.0296	.0202	.0115	.0072	.0049	.0035	.0027
	.563	.314	.067	.022	.0097	.0048	.0027	.0011	.0006	.0003	.0002	.0001
25	.36	.400	,167	.083	.046	.0296	.0206	.0116	.0073	.0050	.0036	.0028
	.36	.283	.075	.026	.011	.0058	.0034	.0014	.00072	.00041	.00026	.00017
30	.25	.311	.155	.0803	.0490	.0304	.0207	.0116	.0074	.0050	00366	.0028
	.25	.240	.089	.0298	.0138	.0071	.0041	.0017	.00089	.00050	.00031	.00021
40	.14	.197	.127	.0725	.0453	.0297	.0208	.0112	.0074	.00518	.0037	.0027
	.14	.167	.079	.0341	.0168	.0090	.0054	.0022	.0012	.00067	.00042	.00027
50	.091	.128	.100	.0645	.0420	.0290	.0207	.0117	.0075	.00512	.00364	.0028
	.091	.115	.072	.0356	.0189	.0108	.0065	.0050	.00146	.00085	.00052	.00034

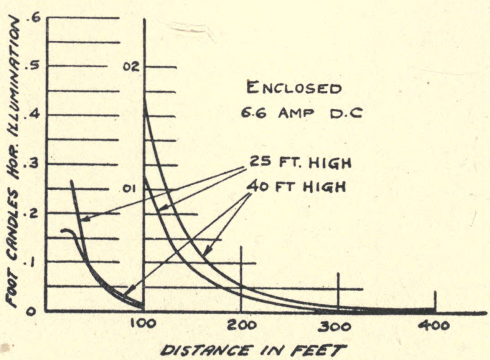

Fig. 16. Horizontal Distribution at Street Surface for a 6.6 Amp. D. C. Enclosed Arc Lamp

TABLE 8

Normal and Horizontal Distribution at Street Surface for 6.6 Amperes A. C. Enclosed Arc Lamp

Height feet	Distance—feet											
	0	25	50	75	100	125	150	200	250	300	350	400
15	.78	.313	.086	.036	.021	.014	.0097	.0053	.0033	.0022	.0016	.0012
	.78	.161	.0247	.0075	.0032	.0017	.00096	.0004	.0002			
20	.44	.259	.077	.038	.022	.014	.0094	.0053	.0034	.0023	.0017	.0013
	.44	.168	.0285	.0097	.0043	.0022	.0012	.0005	.00027			
25	.28	.22	.080	.038	.022	.014	.0095	.0054	.0034	.0024	.0017	.0013
	.28	.156	.032	.012	.0044	.0027	.00156	,0007	.00034			
30	.19	.18	.071	038	.022	.0137	.0094	.0054	.0034	.0023	.0017	.0013
	.19	.139	.0362	.014	.0063	.032	.0018	.0008	.0004	.0002		
40	.11	.124	.067	.036	.022	.0135	.0095	.0054	.0034	.0024	.0017	.0013
	.11	.116	.042	.017	.008	.0041	.0024	.0011	.0005	.0003		
50	.07	.083	.055	.033	.020	.0135	.010	.005	.0034	.0024	.0016	.0013
	.07	.074	.039	.018	.0092	.005	.003	.0022	.0006	.0004	.0002	.0001

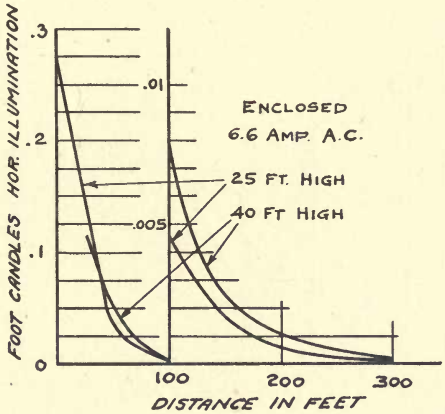

Fig. 17. Horizontal Distribution at Street Surface for a 6.6 Amp. A. C. Enclosed Arc Lamp

TABLE 9

Normal and Horizontal Distribution at Street Surface for 7.5 Amperes A. C. Enclosed Arc Lamp

Height feet	Distance—feet											
	0	25	50	75	100	125	150	200	250	300	350	400
15	.94	.376	.103	.043	.025	.017	.011	.0063	.004	.0022	.0019	.0014
	.94	.193	.030	.009	.0038	.002	.001	.0005	.0002			
20	.53	.311	.092	.045	.026	.017	.011	.0064	.0041	.0027	.0020	.0015
	.53	.201	.e34	.0016	.0051	.0026	.0014	.0006	.0003			
25	.336	.26	.096	.045	,026	.017	.011	,0065	.0041	.0029	.0020	.0015
	.336	.187	.038	.014	.0053	.0032	.0019	.0008	.0004			
30	.228	.216	.085	.045	.026	.0165	.011	.0065	.004	.0028	.002	.0015
	.228	.167	.043	.017	.0076	.0038	.0022	.0011	.0005	.0002		
40	.132	.149	.080	.043	.026	.0162	.011	.0066	.0041	.0029	.0020	.0015
	.132	.139	.050	.020	.0096	.0049	.0029	.0013	.0006	.0004		
50	.084	.10	.066	.040	.024	.016	.012	.006	.0041	.0029	.0019	.0015
	.084	.09	.047	.022	.011	.006	.0036	.0026	.0007	.0005	.0002	.0001

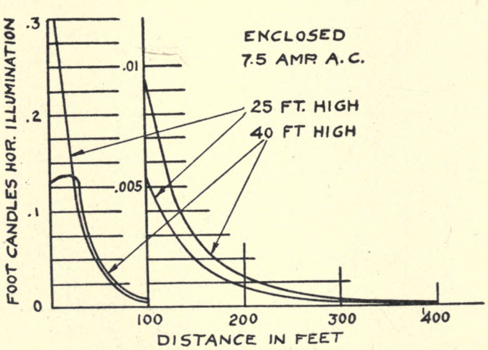

Fig. 18. Horizontal Distribution at Street Surface for a 7.5 Amp. A. C. Enclosed Arc Lamp

TABLE 10

NORMAL AND HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR 10 AMPERES D. C. FLAME ARC LAMP, INCLINED ELECTRODES, OPAL GLOBES

Height feet	Distance											
	0	25	50	75	100	125	150	200	250	300	350	400
15	10.6	2.33	.585	.240	.142	.085	.056	.031	.019	.013	.010	.007
	10.6	1.20	.168	.047	.021	.010	.0055	.0022	.0013	.0006	.0004	.0003
20	5.95	1.70	.595	.259	.136	.084	.057	.031	.020	.013	.010	.008
	5.95	1.28	.224	.066	.027	.0135	.0075	.0031	.0015	.0008	.0005	.0004
25	3.81	1.77	.602	.262	.140	.085	.058	.031	.020	.013	.010	.0075
	3.81	1.25	.265	.084	.034	.017	.010	.004	.002	.0011	.0007	.0005
30	2.65	1.51	.580	.266	.152	.091	.059	.032	.020	.014	.010	.0075
	2.65	1.15	.297	.100	.043	.021	.012	.0047	.0025	.0014	.0008	.0075
40	1.49	1.09	.52	.253	.150	.094	.064	.032	.021	.014	.010	.0077
	1.49	.94	.32	.123	.055	.029	.0165	.0064	.0032	.0018	.0011	.0008
50	.95	.76	.44	.25	.16	.096	.065	.035	.022	.015	.010	.0084
	.95	.68	.315	.138	.072	.036	.021	.0084	.0042	.0024	.0014	.001

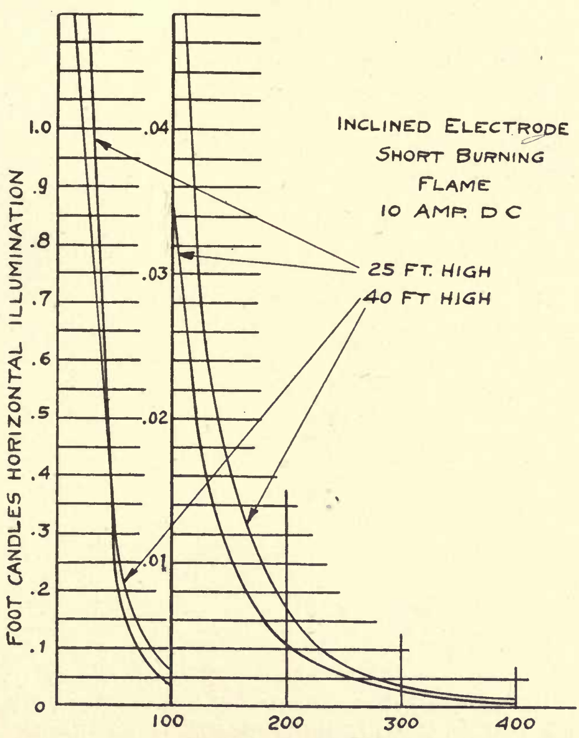

FIG. 19. HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR A 10 AMP. D. C. FLAME ARC LAMP, INCLINED ELECTRODES

TABLE 11

NORMAL AND HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR 5.5 AMPERES D. C. LONG BURNING FLAME ARC LAMP VERTICAL ELECTRODES, OPAL GLOBES

	Distance—feet											
	0	25	50	75	100	125	150	200	250	300	350	400
15	3.38	1.77	.65	.32	.19	.125	.087	.049	.0304	.021	.015	.011
	3.38	.91	.186	.063	.0281	.015	.0087	.0036	.0020	.001	.0006	.0004
20	1.90	1.49	.587	.302	.182	.119	.082	.0485	.031	.021	.0154	.0115
	1.90	.945	.218	.0775	.036	.019	.011	.0048	.0025	.0033	.0009	.0006
25	1.26	1.0	.550	.278	.166	.114	.081	.047	.031	.021	.0156	.012
	1.26	.707	.243	.088	.040	.022	.0132	.0059	.0031	.0018	.0011	.0007
30	.845	.760	.443	.260	.166	.110	.079	.046	.030	.021	.0156	.012
	.845	.657	.225	.095	.047	.0256	.0155	.0068	.0036	.0021	.0013	.0009
40	.475	.458	.398	.214	.146	.101	.075	.043	.03	.021	.015	.0116
	.475	.393	.204	.101	.054	.022	.0193	.0085	.0047	.0027	.0017	.0011
50	.304	.321	.25	.180	.128	.094	.069	.042	.029	.020	.015	.0114
	.304	.287	.176	.10	.057	.035	.0217	.010	.0056	.0034	.0021	.0014

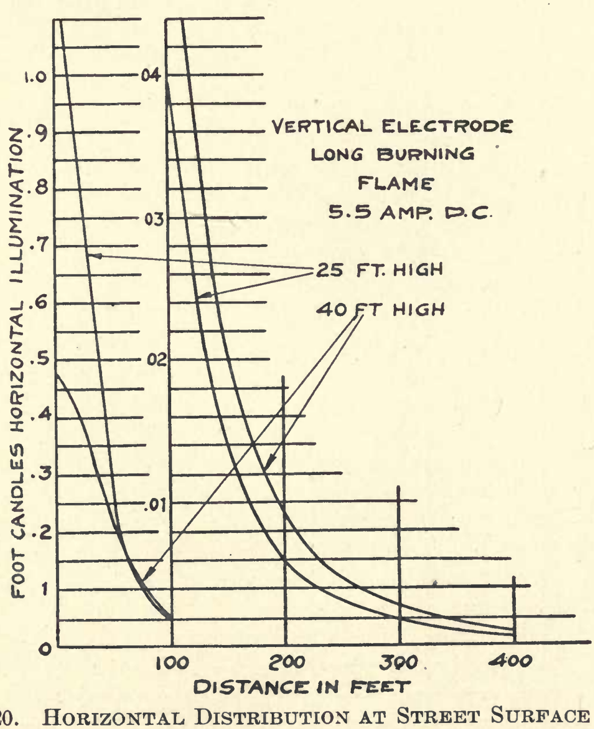

FIG. 20. HORIZONTAL DISTRIBUTION AT STREET SURFACE FOR A 5.5 AMP. D. C. LONG BURNING FLAME ARC LAMP VERTICAL ELECTRODES

TABLE 12

Normal and Horizontal Distribution at Street Surface for 200 C. P. Tungsten with Radial Wave Reflector

Height feet	Distance—feet							
	0	25	50	75	100	125	150	200
15	.643	.316	.097	.043	.026	.015	.0102	.0057
	.643	.163	.028	.0084	.0039	.0018	.0010	.0004
20	.362	.243	.093	.044	.025	.0153	.0105	.0058
	.362	.155	.035	.0112	.0049	.0024	.0014	.0006
25	.232	.200	.086	.0427	.0238	.0154	.0107	.0059
	.232	.141	.035	.0135	.0057	.0030	.0017	.0007
30	.161	.154	.078	.0413	.0251	.0156	.0107	.0060
	.161	.118	.040	.0154	.0071	.0036	.0021	.0009
40	.091	.098	.063	.0376	.0233	.0153	.0108	.006
	.091	.084	.039	.0175	.0086	.0046	.0028	.0011
50	.058	.062	.049	.0326	.0217	.0151	.0106	.006
	.058	.058	.035	.018	.0097	.0054	.0033	.0014

TABLE 13

Normal and Horizontal Distribution at Street Surface for 350 C. P. Tungsten with Fluted Enameled Reflector

Height feet	Distance—feet									
	0	25	50	75	100	125	150	200	250	300
15	1.03[illegible]	.503	.165	.072	.041	.0265	.0179	.010	.0062	.0043
	1.03[illegible]	.259	.0473	.014	.006	.0031	.0018	.00074	.00041	.00021
20	.575	.395	.156	.074	.042	.0256	.0178	.010	.0063	.0043
	.575	.247	.0575	.019	.0082	.0041	.0024	.001	.0005	.00024
25	.370	.324	.141	.0725	.040	.0252	.0180	.017	.0063	.00435
	.370	.230	.063	.023	.0095	.0045	.0030	.0012	.0006	.00036
30	.257	.256	.126	.0685	.0425	.0262	.018	.010	.0063	.0044
	.257	.197	.064	.026	.0120	.0061	.0035	.0015	.00076	.00044
40	.145	.168	.099	.060	.0392	.0259	.0181	.0098	.0064	.0044
	.145	.145	.0615	.0383	.0145	.0079	.0046	.0019	.0010	.00058
50	.093	.111	.081	.052	.0354	.025	.0181	.010	.0065	.0045
	.093	.099	.057	.0288	.0160	.0093	.0057	.0024	.0013	.00074

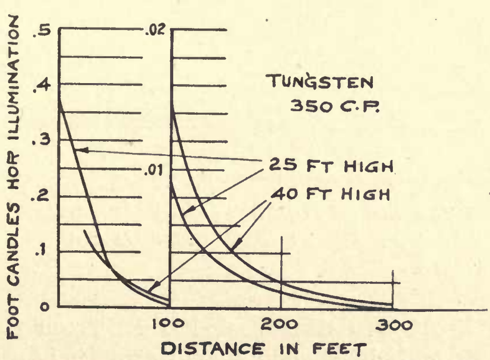

Fig. 21.—Horizontal Distribution at Street Surface for a 350 C. P. Tungsten Lamp with Enamelled Reflector

(b) *Surface Illumination Curves.*—From the data in Tables 4 to 13, curves have been plotted, showing the distribution of illumination over the street surface for each of the lamps. Two curves are plotted in each case, one for a height of 25 ft. and the

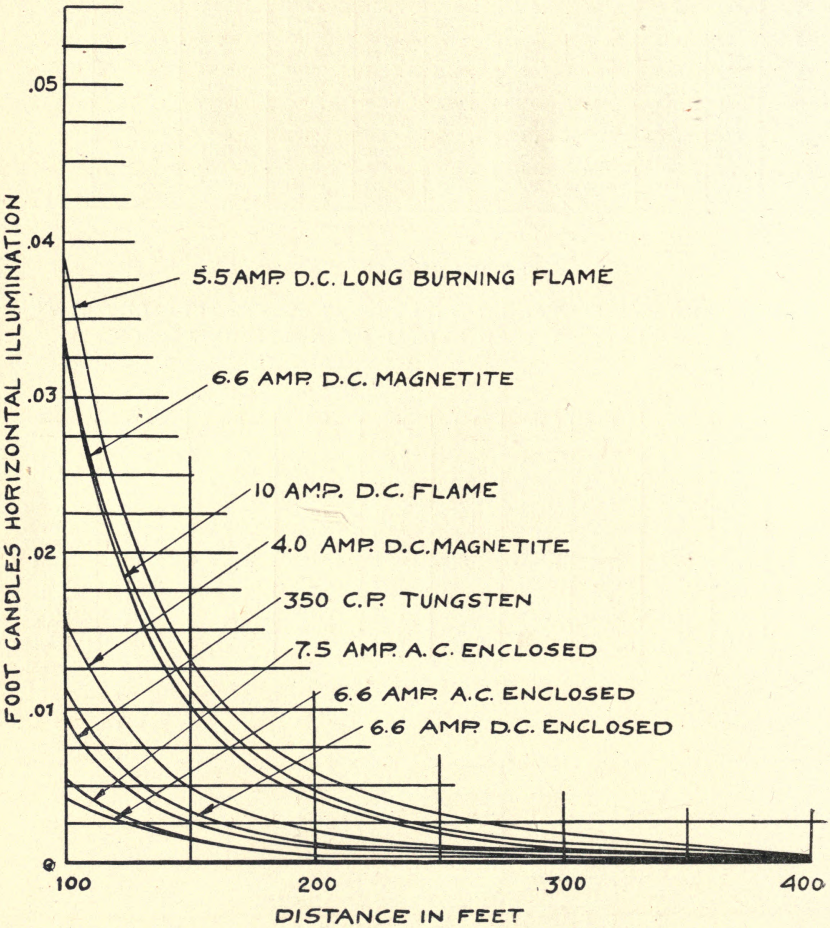

FIG. 22. COMPARISON OF HORIZONTAL DISTRIBUTION AT STREET SURFACE BY DIFFERENT LAMPS

other for 40 ft. At a distance of 100 ft. from the base of the lamp, the illumination has become so low that it is not easily comparable with that near the lamp. In order to read these values

more easily, the foot candle scale has been magnified between 100 and 400 ft. These curves are shown in Fig. 13 to 21. In Fig. 22, a comparison is made between the different lamps between 100 and 400 ft.

In order to indicate the method of computing the distribution of illumination on the street surface due to several lamps, and the effect of height and spacing, the following calculations have been made. Take, as an example, the 6.6 ampere alternating current enclosed arc, suspended 25 and 40 ft. above the center of the street surface, and spaced 800, 400 and 200 ft. apart, these distances being controlled by local conditions. In Fig. 23, OO′ represents the surface of the street and 1-2 lamps. It is obvious that the normal illumination can not be added for lamps on

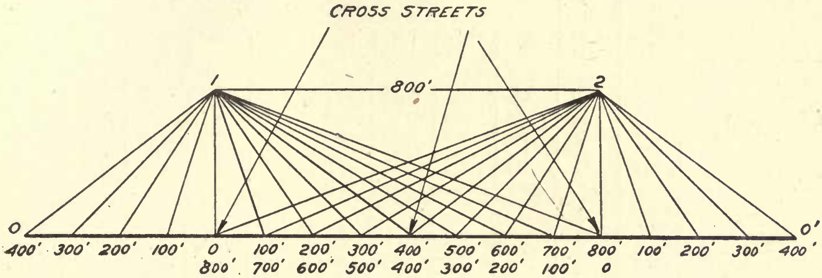

FIG. 23

opposite sides of an object, but that the horizontal is increased. Adding the illumination from the two lights at the various distances, line 1, Table 14 is obtained from Table 8. It is seen that the illumination beyond 400 ft. from the lights is so small that the sum need be considered only at the middle point.

For 400 ft. spacing, line 2 is obtained from the two lights 1-2 at street intersections (see Fig. 24). It will be seen that the

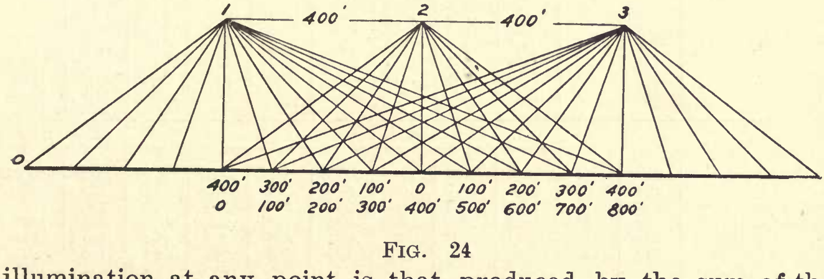

FIG. 24

illumination at any point is that produced by the sum of the illuminations from all lights at their respective distances from that point. Only two lights need be considered at 400 ft. At 200 ft. it will be found that four lights must be considered. In each

case, the maximum illumination is affected but little, but the general effect becomes better. For 200 ft. spacing, line 3, Table 14 is computed. In a similar manner, the illumination for other types of lights has been computed. These are also illustrated in Table 14. These values have not been plotted in the form of curves.

TABLE 14

Horizontal Distribution at Street Surface for Different Heights and Spacings

	Spacing feet	h feet	Distance—feet								
			0	50	100	150	200	250	300	350	400
6.6 Amp. D. C. Enclosed	800	25	.36	.075	.011	.0034	.0014	.0007	.0004	.0004	.0004
	400	25	.36	.075	.011	.04	.003	.004	.011	.075	.36
	200	25	.372	.082	.023	.082	.372	.082	.023	.082	.372
	800	40	.14	.079	.0168	.0054	.0022	.0012	.0007	.0006	.0006
	400	40	.14	.08	.017	.0066	.0044	.0066	.017	.08	.14
	200	40	.142	.085	.034	.085	.142	.085	.034	.085	.142
7.5 Amp. A. C. Enclosed	800	25	.336	.038	.005	.0019	.0008	.0004	.0003	.0002	.0001
	400	25	.336	.038	.0053	.0023	.0016	.0023	.0053	.038	.336
	200	25	.34	.05	.012	.05	.34	.05	.012	.05	.34
	800	40	.132	.05	.0096	.003	.0013	.0006	.0004	.0003	.0002
	400	40	.132	.05	.011	.0035	.0026	.0035	.011	.05	.132
	200	40	.135	.10	.022	.10	.135	.10	.022	.10	.135
6.6 Amp. D. C. Magnetite	800	25	.80	.225	.034	.0111	.0046	.0024	.0013	.001	.001
	400	35	.80	.226	.035	.0135	.0092	.0135	.035	.226	.80
	200	25	.85	.238	.069	.238	.85	.238	.069	.235	.85
	800	40	.315	.205	.047	.0163	.0073	.0039	.0022	.002	.0016
	400	40	.316	.206	.049	.020	.014	.020	.049	.206	.316
	200	40	.329	.225	.096	.225	.329	.225	.096	.225	.329
4.0 Amp. D. C. Magnetite	800	25	.56	.095	.016	.005	.002	.001	.0016	.0006	.0005
	400	25	.56	.095	.016	.006	.004	.006	.016	.095	.56
	200	25	.564	.101	.033	.101	.564	.101	.033	.101	.564
	800	40	.219	.092	.022	.0077	.0033	.0018	.001	.0009	.0008
	400	40	.219	.092	.044	.0095	.0066	.0095	.044	.092	.219
	200	40	.222	.094	.044	.094	.222	.094	.044	.094	.222
9.6 Amp. D. C. Open	800	25	.08	.133	.013	.0035	.0014	.0007	.0004	.0003	.0003
	400	25	.08	.133	.013	.042	.0028	.042	.013	.133	.08
	200	25	.081	.136	.026	.136	.081	.136	.026	.136	.081
	800	40	.031	.185	.026	.006	.002	.001	.0007	.0006	.0005
	400	40	.031	.185	.026	.007	.004	.007	.026	.185	.031
	200	40	.035	.192	.053	.192	.035	.192	.053	.192	.035

TABLE 14 (*Continued*)

	Spacing feet	h feet	Distance—feet 0	50	100	150	200	250	300	350	400
Long Burning Flame Vertical	800	25	1.26	.243	.040	.0132	.0059	.0031	.002	.0016	.0014
	400	25	1.26	.244	.042	.0163	.012	.0163	.042	.244	1.26
	200	25	1.27	.261	.084	.261	1.27	.261	.084	.261	1.27
	800	40	.475	.204	.054	.0193	.0085	.0047	.0029	.0023	.0022
	400	40	.476	.206	.057	.024	.017	.024	.057	.206	.476
	200	40	.486	.230	.114	.230	.486	.230	.114	.230	.486
Flame Arc Inclined	800	25	3.81	.265	.034	.010	.004	.002	.001	.001	.001
	400	25	3.81	.266	.035	.012	.008	.012	.035	.266	3.81
	200	25	3.82	.276	.07	.276	3.82	.276	.07	.276	3.82
	800	40	1.49	.32	.055	.0165	.0064	.0032	.0021	.0017	.0016
	400	40	1.49	.32	.057	.0168	.0128	.0168	.057	.32	1.49
	200	40	1.50	.34	.112	.34	1.50	.34	.112	.34	1.50
6.6 Amp. A. C. Enclosed	800	25	.28	.032	.0044	.0016	.0007	.0003			
	400	25	.28	.032	.0044	.0016	.0014	.0016	.0044	.032	.28
	200	25	.28	.035	.009	.035	.28	.035	.009	.035	.28
	800	40	.11	.042	.008	.0024	.0011	.0005	.0003		
	400	40	.11	.042	.008	.003	.0022	.003	.008	.042	.11
	200	40	.11	.045	.016	.045	.11	.045	.016	.045	.11
350 C. P. Tungsten	800	25	.37	.063	.0095	.003	.0012	.0006	.0004	.0002	.0002
	400	25	.37	.032	.01	.004	.0024	.004	.01	.032	.37
	200	25	.37	.038	.025	.038	.37	.038	.025	.038	.37
200 C. P. Tungsten	400	20	.362	.035	.011	.005	.003	.005	.011	.035	.362
	200	20	.365	.04	.023	.04	.365	.04	.023	.04	.365
	d	h	0	25	50	75	100	125	150	175	200
100 C. P. Tungsten	200	20	.181	.078	.015	.0068	.005	.068	.018	.078	.181
	100	20	.183	.084	.034	.084	.183	.084	.034	.084	.183
60 C. P. Tungsten	200	20	.11	.046	.01	.004	.003	.004	.01	.046	.11
	100	20	.11	.052	.021	.052	.11	.052	.021	.052	.11
32 C. P. Tungsten	200	20	.06	.024	.005	.002	.002	.002	.005	.024	.06
	100	20	.09	.028	.010	.028	.06	.028	.010	.028	.06

VI. Street Lighting

Street lighting in different parts of a city must serve various purposes. For utility and safety, the business streets require a different treatment from the residence streets and suburban districts. Parks and open places require a still different arrangement of lights. A good division of the city is the following:

A Principal business streets;
B Important cross streets and boulevards;
C Residence streets;
D Outlying districts.

14. *Business Streets.*—In the principal business streets, the illumination should be more or less brilliant. It should be as uniform as possible, and of sufficient intensity to enable one to read ordinary sized print, i.e., at least .25 to 1 foot candle. In many cities in Europe, the inclined carbon flame arc is used for these streets. The lamps are suspended over the center of the street from tall ornamental poles on both sides, and at a height of from 40 to 50 ft. They are spaced from four to five times their height. These produce a very beautiful effect, and the street is brightly illuminated. With the reflection from buildings, the illumination averages about two foot candles. This lighting is also carried out for short distances into the cross streets. In this country, the flame arc has not met with favor on account of the high operating cost for the short burning arc. With the advent of the more modern long burning flame arc, this objection can not be made, since, in lighting from large units spaced comparatively near together, the number of the lights will be nearly inversely to the mean lower hemispherical candle power. This will be more apparent later. The standard for such lighting has not yet been set in this country. There is now a strong tendency towards clusters of tungsten lights, or arc lights on ornamental poles, placed low on both sides of the street. It is claimed justly that the best lighted streets attract the crowds and hence merchants are insisting upon brighter and brighter illumination on their streets, even assisting the city in meeting the additional cost of maintenance.

15. *Cross Streets and Boulevards.*—The boulevards and cross streets require a much less brilliant illumination. The principal cross streets do not usually have shade trees, and may be lighted either by high intensity lamps suspended high or low intensity lamps more closely spaced and supported low. The general characteristics of the streets will indicate the type of lighting to be used. In such streets, heavy slow moving traffic is usual. The

boulevards, on the other hand, are usually shaded and require the lights to be suspended low unless the streets are very wide. For shaded streets, lights upon ornamental poles at the sides of the streets are preferable to those suspended over the center, on account of the character of the street. By this is meant that since such a street is used mostly for light vehicles, moving more or less rapidly, lights should not be hung so as to blind the drivers. The appearance of such a street is improved by side lighting, or lights suspended fairly high over the center of wide streets. Probably from .10 to .5 foot candle is a good figure to use.

16. *Residence Streets.*—Residence streets should have one light at each street crossing, for the safety of vehicles and pedestrians approaching these crossings, as collisions are more liable to occur at such points. These streets are usually rather narrow and densely shaded, thus requiring the lights to be supported not over 15 to 25 ft. above the street surface. The maximum illumination should not be too high or the minimum too low. The general average of the illumination should, however, be low. The character and color of the surface has a marked effect upon the lighting of such streets. It is well known that a street with snow upon its surface appears much better lighted than the same one when the snow has disappeared. It is usual in dim illumination to see nearly all obstructions as dark objects against the lighter background of the lighted street. Such a contrast is more distinct if the background is lighter. A macadamized road or asphalt pavement needs much more illumination than one paved with light bricks. It will be seen from Tables 4 to 13 that lights will not give good illumination at the middle of blocks 400 ft. long, if the lights are 25 ft or less above the street. The illumination in the immediate neighborhood of most arc lights is also higher than necessary for this class of street. In crooked streets or where the surface is uneven or hilly, lights must be spaced more closely than at every street crossing. Residence street lighting is the particular field for the incandescent light. In choosing a light for this class of service, the economic limit comes in the ordinary spacing of poles on the street, and the lowest value of illumination allowable immediately below the light. A street having many small lights, hung low and spaced rather closely together, has long been associated with the narrow street of the poorer quarter with its dingy appearance. The brilliant effect and white light from the tungsten light has done much to dispel this prejudice.

17. *Outlying Districts.*—In the outlying districts, either the tungsten light or an arc light having low operating cost may be used. It is seldom that a community can afford to have an arc light at each street intersection in such a district. Hence for protection and safety, the tungsten light may be used to good advantage. A difference here may also be made between streets connecting trade centers and cross streets. The former may be treated as boulevards or as residence streets, according to the traffic conditions.

It is thus seen that no specific rules can be laid down in street lighting. Each case to be handled is more or less special. However in choosing a general lighting scheme for any city, the central station furnishing the power must also be considered. It would of course, not be feasible to specify a variety of lights, requiring varied generating apparatus. In any system, the station apparatus should be interchangeable from one circuit to another for continuity of service and low first cost and maintenance. Thus, if D. C. lamps are chosen, they should all have the same current consumption and this should also fit well with incandescent lamps on the market. On the other hand small compensators may be supplied with each A. C. lamp to adapt it to any A. C. circuit. Wires in series circuits have a voltage upon them at the station, dangerous to personal safety. The circuit may become accidentally grounded at some point, either by contact with a telephone wire or the limb of a tree when wet. In such case, the full voltage may exist between the other wire and ground. Hence, for safety to persons, these wires should not be allowed too near the ground. They are usually required to be strung on the upper cross arm of the poles. If they are brought down to incandescent lamps, suspended too low or strung on low poles, serious accidents are liable to occur. To avoid this, especially low poles should not be used for series lighting. For such service, tungsten multiple 110 volt lamps may be used from special feeder circuits or series lights on ornamental posts fed from armored cables buried in the ground. This latter applies especially to ornamental park lighting.

VII. Cost of Operation

The choice of a lamp for a given class of street lighting depends upon the illumination which may be obtained from the lamp and upon its cost of operation. A flat rate is usually made for street lighting; i. e., a charge of so many dollars per lamp per

year. The items which enter into a consideration of these charges are:

A Fixed charges;
B Maintenance charges;
C Energy charge.

These items, together with the number of hours in operation, or schedule, determine the rate to be charged for the service. These will be considered in the order named.

18. *Fixed Charges.*—In this item is considered a charge of 6 per cent, covering interest on the capital invested, taxes, insurance, etc., and a depreciation charge of 10 per cent. This latter charge, if deposited at 5 per cent in a sinking fund, would replace the equipment in from eight to nine years. With the present rapid advance in the development of lamps, this figure seems conservative. It means that replacement is due to advance in the art, rather than to the complete deterioration of the apparatus. On the other hand, the depreciation charge depends also upon the life of the city ordinance. If the ordinance is for five years, the depreciation should be 18 per cent instead of 10 per cent, since the city may require an entire change of its system at the end of the contract or award the contract to some other competing company.

19. *Maintenance Charges.*—In the following table, this charge is itemized and computed on the basis of 1000 hours' operation. It covers the cost of renewals, due to the consumption of electrodes, breakage of glassware, repairs to the mechanism of the lamp, and a charge for labor in trimming, cleaning of glassware and reflectors, inspection, store room charges, etc. These figures represent an average installation, say of 400 arc lamps or their equivalent in incandescent lamps. The trimming cost for tungsten lamps is low on account of the long life of these units. The arc lamps are supposed to be cleaned and inspected by the trimmer. In the case of the tungsten lamps, it is assumed that the reflectors will be thoroughly inspected and cleaned each time the lamps are renewed and also at regular intervals, say four times per year, independent of the schedule. Hence this cleaning charge is placed as an annual charge instead of on the basis of 1000 hours.

20. *Energy Charge.*—Energy is usually computed upon the basis of the kilowatt hours consumed. For convenience of comparison, the cost of energy at the lamp terminals, rather than at the station switchboard, is considered here. The energy charge will then cover the cost of delivering this power, such as depreci-

ation on station apparatus, poles, wires, etc., and the maintenance charges on the same. In order to compare direct and alternating current lamps operated from the same station, the cost of the rectifier outfit is included in the cost of the direct current lamps, and its depreciation charge is placed there also. The efficiency of a rectifier outfit may be taken as 87.5 per cent. The loss of energy must therefore be charged to the D. C. lamps. This charge is made by increasing the cost of energy in line 31, Table 15, inversely in the ratio of the efficiency to 100 per cent. These values are then used in Tables 17 and 18 and in line 31, Table 15. No accurate information is available as to the energy charge for the different stations of this State. Tables 15 and 16 have been computed with an energy charge of one cent per kilowatt hour. From Tables 15 and 16, Tables 17 and 18 have been computed for two schedules and an energy charge from one cent to five cents per kilowatt hour. Curves have also been drawn between energy charge and cost of operation per lamp per year for two different schedules. These are shown in Fig. 25 to 28. They show a ready comparison between the operating cost of the different lamps chosen. There are many factors which affect the cost of energy in different cities. Some of these are the following:

A Cost of coal delivered at the power plant;

B Available water power or natural gas;

C Cost of the land on which the plant is located and taxes on the same;

D Amount of power developed and the load factor;

E Available market for steam heat;

F Cost of delivering the power to the consumer, (under this item will come type of construction, whether pole lines or conduits and taxes or rentals on the same);

G Interest and depreciation on the equipment.

These items vary so widely in different localities that the writers have not attempted to make any definite statements.

21. *Schedules.*—There are numerous schedules in use in this country. The "all night and every night", or 4000 hours per year schedule is used in most cities having a population of 20,000 and over. In smaller cities and suburban districts, various moonlight schedules are in use, the average of these being about 2500 hours per year. This latter schedule is supposed to approximate moonlight every night in the year. The intensity of illumination at the first or last quarter of the moon is only about one-tenth of that

at full moon instead of one-half as might be supposed. Hence the moonlight schedule should be more nearly three-fourths of the all night schedule, instead of from one-half to five-eighths that amount. In small cities, where only a few circuits are necessary, and where a duplicate set of station equipment cannot be afforded, the all night and every night schedule may be approximated by allowing four nights each month near full moon when the lights on certain circuits may be turned off, allowing the necessary repairs to be made. Many other schedules are also in use but are not listed here. Calculations covering the cost of operation of lamps may be made in a manner similar to those for Tables 17 and 18.

Cost Tables

To illustrate how the values in Table 17 are derived the following problem is chosen.

Problem.—Assume a 6.6 amperes, alternating current, enclosed arc lamp to be operating on a 4000 hour schedule, the energy costs being three cents per kilowatt hour. What will be the cost of operating this lamp for one year?

From Table 4.—

For 1000 Hours and One Cent per Kilowatt Hour, (See Table 15):

Annual fixed charges	$3.20
Maintenance per 1000 hours	2.30
Energy per 1000 hours at one cent	4.25

For 4000 Hours at Three Cents per Kilowatt Hour,

Annual fixed charges	$3.20
Maintenance charges for 4000 hours=4×2.30=	9.20
Energy for 4000 hours at three cents=4×3×4.25=	51.00
Total charge per lamp per year,	$63.40

A total charge of $70.00 per lamp per year would represent a fair profit to the central station.

An analysis of the three factors entering into the operating cost of street lamps may be made from Tables 15 to 18. It is at once apparent that none of the factors may be omitted safely for any of the lamps. The greater the number of hours burning per year, the less the importance of the fixed charge. On the other hand, the shorter the schedule, the more important the fixed charge, and the less the importance of the maintenance and energy charges. Another fact clearly shown is the effect upon annual cost of the length of life of the electrodes per trim. The

TABLE 15

Cost and Operating Characteristics of Arc Lamps

	ITEMS	Open Arc D. C. Twin Carbon	Enclosed Arc. D. C.	Enclosed Arc A. C.	Enclosed Arc A. C.	Magnetite Arc D. C.	Magnetite Arc D. C.	Flame Arc D. C. Inclined Carbon	Flame Arc A. C. Inclined Carbon	Flame Arc D. C. Vertical Carbon Long Burning	Flame Arc A. C. Vertical Carbon Long Burning
1	Voltage across lamp terminals.........	50	72	72	72	80	80	55	55	70	70
2	Current..................................	9.6	6.6	7.5	6.6	6.6	4.0	10	10	5.5	5.5
3	Terminal watts..........................	480	475	480	425	528	320	550	467	385	350
4	Maximum candle power value.........	1250	525	350	275	1600	730	2400	—	2575	1925
5	Maximum candle power angle with vertical..............................	45°	65°	40°	40°	80°	80°	0°-30°	—	70°	85°
6	Mean lower hemispherical candle power (H. S. C. P.)......	800	468	298	244	1170	457	1785	850	1800	1485
7	Watts per H. S. C. P....................	.6	1.01	1.61	1.71	.45	.70	.31	.55	.26	.24
8	Kind of glassware, inner globe.........	None	Opal	Opal	Opal	None	None	None	None	Clear	Clear
9	" " " outer "	Clear	Clear	Clear	Clear	Clear	Clear	Opal	Clear	Opal	Clear
10	Curve sheet, figure......................	3 A	4 C	4 B	4 A	3 B	3 C	5 D	—	5 C	—
11	Life positive electrode, hours..........	17	125	100	110	1500	4000	17	17	70	100
12	" negative " "	17	125			100	175	17		70	100
13	" inner globe...........................	—	400	400	400	—	—	—	—	300	300
14	" outer "	1000	2000	2000	2000	2000	2000	1000	1000	2000	2000
15	Cost of lamp, dollars....................	15.00	34.50	20.00	20.00	40.00	40.00	60.00	60.00	60.00	60.00
16	" " positive electrodes, dollars per trim..................................	.015	.021	.022	.022	.50	.45	.14	.14	.25	.25
17	Cost of negative electrodes, dollars per trim..................................					.06	.05				
18	Cost of inner globe, dollars each.......	—	.15	.15	.15	—	—	—	—	.50	.50
19	" " outer " " "	.50	.50	.50	.50	1.00	1.00	1.00	1.00	.75	.75
20	" " labor in trimming, etc., per trim	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06

	A. FIXED CHARGES, ANNUAL										
21	Interest on investment at 6%	.90	2.07	1.20	1.20	2.40	2.40	3.60	3.60	3.60	3.60
22	Depreciation at 10%	1.50	3.45	2.00	2.00	4.00	4.00	6.00	6.00	6.00	6.00
23	Total annual fixed charge	2.40	5.52	3.20	3.20	6.40	6.40	9.60	9.60	9.60	9.60
	B. MAINTENANCE CHARGES PER 1000 HOURS										
24	Cost of electrodes, dollars	.89	.17	.22	.20	.93	.40	8.23	8.23	3.56	2.50
25	" " inner globes, dollars	—	.37	.37	.37	—	—	—	—	1.67	1.67
26	" " outer " "	.50	.25	.25	.25	.50	.50	1.00	1.00	.37	.37
27	" " trimming and inspection, dollars	3.54	.48	.60	.55	.60	.34	3.54	3.54	.85	.60
28	Cost of rectifier renewals, dollars	—	.50	—	—	.50	.50	.50	—	.50	—
29	" " repairs, dollars	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
30	" " maintenance, total, dollars	5.43	2.27	1.94	1.87	3.03	2.24	13.77	13.27	7.45	5.64
	C. COST OF ENERGY, PER 1000 HOURS	*									
31	At one cent per kilowatt hour	4.80	5.42	4.80	4.25	6.05	3.65	6.25	4.67	4.40	3.50

* Line 31 has been computed from line 3, considering the rectifier efficiency.

TABLE 16

COST AND OPERATING CHARACTERISTICS OF TUNGSTEN LAMPS

	ITEMS	For Suspension in Place of Arc					For Suspension at Side of Street				
1	Candle power horizontal	32	60	100	200	350	32	60	100	200	350
2	Terminal watts	38	71	118	236	413	38	71	118	236	413
3	Watts per mean horizontal candle power	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
4	Mean hemispherical candle power (with reflector)	43	80	135	227	471	43	80	135	227	471
5	Watts per H. S. C. P.	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
6	Maximum candle power, value	45	84	140	280	490	45	84	140	280	490
	Maximum candle power, angle with vertical	70°	70°	70°	70°	70°	70°	70°	70°	70°	70°
7	Curve sheet, figure										
8	Life of lamp, hours	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
9	Cost of lamp, dollars	1.00	1.00	1.20	2.44	3.75	1.00	1.00	1.20	2.44	3.75
10	" " labor for inspection and cleaning, annual	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
11	Cost of fixtures, dollars	1.50	1.50	2.00	2.50	2.50	5.00	5.00	5.00	5.00	5.00
12	" " lamp and fixtures	2.50	2.50	3.20	4.94	6.25	6.00	6.00	6.20	7.44	8.95
	A. FIXED CHARGES, ANNUAL										
13	Interest on investment at 6%	.15	.15	.17	.30	.37	.36	.36	.37	.45	.52
14	Depreciation at 10%	.25	.25	.32	.49	.63	.60	.60	.62	.74	.87
15	Annual inspection charge	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
16	Total annual fixed charges	.80	.80	.89	1.19	1.40	1.36	1.36	1.39	1.59	1.79
	B. MAINTENANCE CHARGES PER 1000 HOURS										
17	Cost of lamp renewals, dollars	.74	.74	.83	1.80	2.80	.74	.74	.83	1.80	2.80
18	" " repairs	.05	.05	.05	.10	.10	.15	.15	.15	.15	.15
19	" " maintenance total	.79	.79	.88	1.90	2.90	.89	.89	.98	1.95	2.95
	C. COST OF ENERGY PER 1000 HOURS										
20	At one cent per kilowatt hour	.38	.71	1.18	2.36	4.13	.38	.71	1.18	2.36	4.13

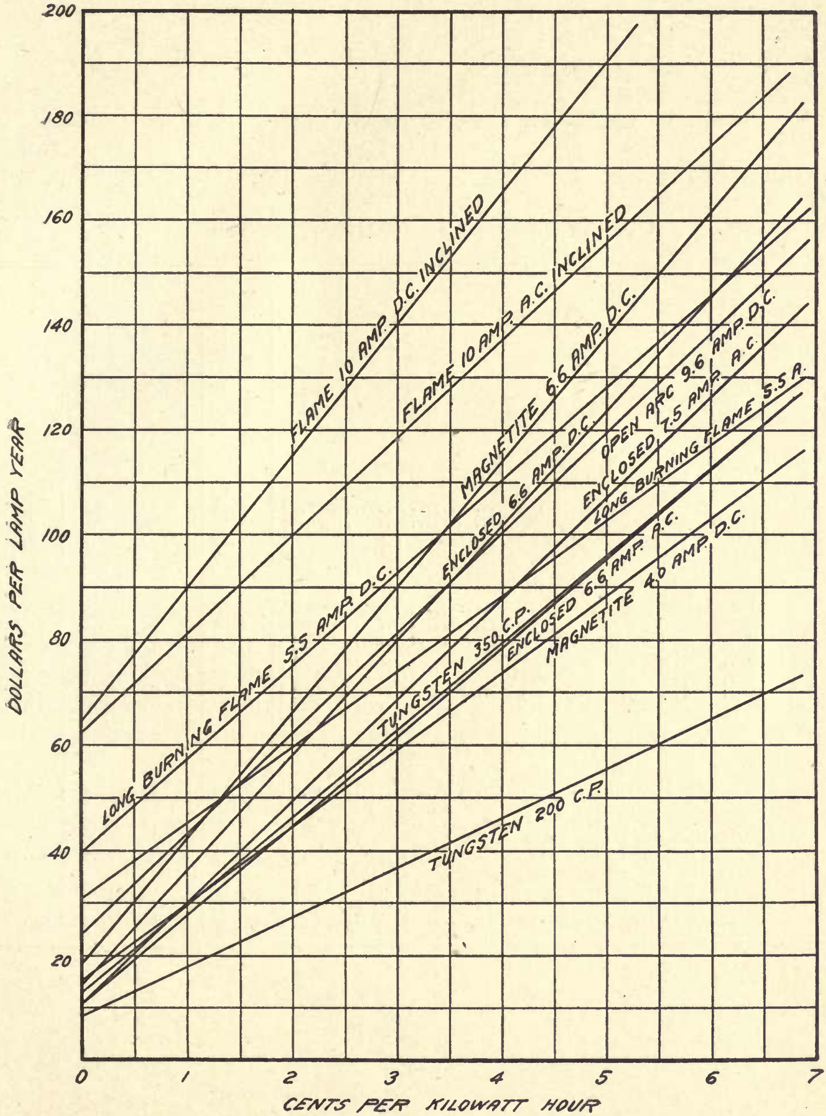

FIG. 25. CURVES SHOWING ANNUAL OPERATING COST OF ARC LAMPS ON 4000-HR. SCHEDULE

TABLE 17

OPERATING COST ON 4000-HOUR SCHEDULE

	ITEMS	Open Arc Twin Carbon D. C.	Enclosed D. C.	Enclosed A. C. 7.5 Amp.	Enclosed A. C. 6.6 Amp.	Magnetite 6.6 Amp.
	FOR 1000 HOURS FROM TABLE					
1	Annual fixed charge	2.40	5.52	3.20	3.20	6.40
2	Maintenance for 1000 hours	5.42	2.27	1.94	1.87	3.03
3	Energy per 1000 hours at 1 cent per K. W. Hr.	4.80	5.42	4.80	4.25	6.05
	ANNUAL COST 4000 HOUR SCHEDULE					
4	Annual fixed charge (1)	2.40	5.52	3.20	3.20	6.40
5	Maintenance, 4 × (2)	21.68	9.08	7.76	7.48	12.12
6	Energy at 1 cent, 4 × (3)	19.20	21.70	19.20	17.00	24.20
7	" " 2 cents, 2 × 4 × (3)	38.40	43.40	38.40	34.00	48.40
8	" " 3 " , 3 × 4 × (3)	57.60	65.20	57.60	51.00	72.60
9	" " 4 " , 4 × 4 × (3)	76.80	86.80	76.80	68.00	96.80
10	" " 5 " , 5 × 4 × (3)	96.00	108.50	96.00	85.00	111.00
	TOTAL ANNUAL OPERATING COST					
11	Total cost per lamp, 1 cent per K. W. Hr. (4) + (5) + (6)	43.28	36.30	30.16	27.68	42.72
12	Total cost per lamp, 2 cents per K. W. Hr. (4) + (5) + (7)	62.48	58.00	49.36	44.68	66.92
13	Total cost per lamp, 3 cents per K. W. Hr. (4) + (5) + (8)	81.68	79.80	68.56	61.68	91.12
14	Total cost per lamp, 4 cents per K. W. Hr. (4) + (5) + (9)	100.88	101.40	87.76	78.68	105.32
15	Total cost per lamp, 5 cents per K. W. Hr. (4) + (5) + (10)	120.08	123.10	106.96	95.68	129.52

TABLE 17 (*Continued*)

4000–HOUR SCHEDULE

Magnetite 4.0 Amp.	Flame D. C. Inclined	Flame A. C. Inclined	Flame D. C. Vertical Long Burning	Flame A. C. Vertical Long Burning	Center Suspension					Side Suspension				
					Tungsten 32 C. P.	Tungsten 60 C. P.	Tungsten 100 C. P.	Tungsten 200 C. P.	Tungsten 350 C. P.	Tungsten 32 C. P.	Tungsten 60 C. P.	Tungsuen 100 C. P.	Tungsten 200 C. P.	Tungsten 350 C. P.
6.40	9.60	9.60	9.60	9.60	.80	.80	.84	1.19	1.40	1.36	1.36	1.39	1.59	1.79
2.24	13.77	13.27	7.45	5.64	.79	.79	.88	1.90	2.90	.89	.89	.98	1.95	2.95
3.65	6.25	4.67	4.40	3.50	.38	.71	1.18	2.36	4.13	.38	.71	1.18	2.36	4.13
6.40	9.60	9.60	9.60	9.60	.80	.80	.84	1.19	1.40	1.36	1.36	1.39	1.59	1.79
8.96	55.08	53.08	29.80	22.56	3.16	3.16	3.52	7.60	11.60	3.56	3.56	3.92	7.80	11.80
14.60	25.20	18.68	17.60	14.00	1.52	2.84	4.72	9.44	16.52	1.52	2.84	4.72	9.44	16.52
29.20	50.40	37.36	35.20	28.00	3.04	5.68	9.44	18.88	33.04	3.04	5.68	9.44	18.88	33.04
43.80	75.60	56.04	52.80	42.00	4.52	8.52	14.16	28.32	49.56	4.56	8.52	14.16	28.32	49.56
58.40	100.80	74.72	70.40	56.00	6.08	11.36	18.88	37.76	66.08	6.08	11.36	18 88	37.60	66.08
73.00	126.00	93.40	86.00	70.00	7.60	14,20	23.60	47.20	82.60	7.60	14.20	23.60	47.20	82 60
29.96	89.88	81.36	57.00	46.16	5.48	6.80	9.08	18.23	29.52	6.44	7.76	10.03	18.83	30.11
34.56	115.08	100.04	74.60	60.16	7.00	9.64	13.80	27.67	46.04	7.96	10.60	14.75	28.27	46.63
59.16	140.28	118.72	92.20	74.16	8.52	12.48	18.52	37.11	62.56	9.48	13.44	19.47	37.79	63.15
73.76	165.48	137.40	109.80	88.16	10.04	15.32	23.24	46.55	79.08	11.00	16.28	24.19	47.15	79.67
88.36	190.68	156.08	125.40	102.16	11.56	18.16	27.96	55.99	95.60	12.52	19.12	28.91	56.59	96.19

TABLE 18

OPERATING COST ON 2500-HOUR SCHEDULE

	Items	Open Arc Twin Carbon D. C.	Enclosed D. C.	Enclosed A. C. 7.5 Amp.	Enclosed A. C. 6.6 Amp.	Magnetite 6.6 Amp.
	FOR 1000 HOURS FROM TABLE					
1	Annual Fixed Charge....	2.40	5.52	3.20	3.20	6.40
2	Maintenance For 1000 hours....	5.42	2.27	1.94	1.87	3.03
3	Energy Per 1000 hours at 1 cent Per K. W. Hour	4.80	5.42	4.80	4.25	6.05
	ANNUAL COST 2500 HOUR SCHEDULE					
4	Annual Fixed Charge (1)	2.40	5.52	3.20	3.20	6.40
5	Maintenance, 2.5 x (2)....	13.55	5.67	4.85	4.67	7.57
6	Energy at 1 cent, 2.5 x (3)....	12.00	13.55	12.00	10.62	15.10
7	Energy at 2 cents, 2.5 x 2 x (3)....	24.00	27.11	24.00	21.24	30.20
8	Energy at 3 cents, 2.5 x 3 x (3)....	36.00	40.70	36.00	31.86	45.30
9	Energy at 4 cents, 2.5 x 4 x (3)....	48.00	54.30	48.00	42.48	60.40
10	Energy at 5 cents, 2.5 x 5 x (3)....	60.00	67.70	60.00	53.10	75.50
	TOTAL ANNUAL OPERATING COST					
11	Total Cost Per Lamp, 1 cent Per K. W. Hr. (4) + (5) + (6)	27.95	24.74	20.05	18.49	29.07
12	Total Cost Per Lamp, 2 cents Per K. W. Hr. (4) + (5) + (7)	39.95	38.30	32.05	29.11	44.17
13	Total Cost Per Lamp, 3 cents Per K. W. Hr. (4) + (5) + (8)....	51.95	51.89	44.05	39.73	59.27
14	Total Cost Per Lamp, 4 cents Per K. W. Hr. (4) + (5) + (9).	63.95	65.49	56.05	50.35	74.37
15	Total Cost Per Lamp, 5 cents Per K. W. Hr. (4) + (5) + (10)....	75.95	78.89	68.05	60.97	89.47

TABLE 18 (*Continued*)

2500-Hour Schedule

Magnetite 4.0 Amp.	Flame D. C. Inclined	Flame A. C. Inclined	Flame D. C. Vertical Long Burning	Flame A. C. Vertical Long Burning	Center Suspensions					Side Suspension				
					Tungsten 32 C. P.	Tungsten 60 C. P.	Tungsten 100 C. P.	Tungsten 200 C. P	Tungsten 350 C. P.	Tungsten 32 C. P.	Tungsten 60 C. P.	Tungsten 100 C.P	Tungsten 200 C. P.	Tungsten 350 C.H,
6.40	9.60	9 60	9.60	9.60	.80	.80	.84	1.19	1.40	1.36	1.36	1.39	1.59	1.79
2.24	13.77	13.27	7.45	5.64	.79	.79	.88	1.90	2.90	.89	.89	.98	1.95	2.95
3.65	6.25	4.67	4.40	3.50	.38	.71	1.18	2.36	4.13	.38	.71	1.18	2.36	4.13
6.40	9.60	9.60	9.60	9.60	.80	.80	.84	1.19	1.40	1.36	1.36	1.39	1.59	1.79
5.60	34.42	33.11	18.62	14.10	1.97	1.97	2.20	4.75	7.25	2.22	2.22	2.45	4.87	7.37
9.14	15.70	11.67	11.00	8.75	.95	1.77	2.95	5.90	10.32	.95	1.77	2.95	5.90	10.32
18.30	31.40	23.34	22.00	17.50	1.90	3.54	5.90	11.80	20.64	1.90	3.54	5.90	11.80	20.64
27.40	47.10	35.01	33 00	26.25	2.85	5.31	8.85	17.70	30.96	2.85	5.31	8.85	17.70	30.96
36.50	62.80	46.68	44.00	35.00	3.80	7.08	11.80	23.60	41.28	3.80	7.08	11.90	23.60	41.28
45.70	78.60	58.35	55.00	43.75	4.75	8.85	14.75	29 50	51.60	4.75	8.85	14.75	29.50	51.60
21.14	59.72	54.44	39.22	32.45	3.72	4.54	5.99	11.84	18.97	4.53	5.35	6.79	12.36	19.48
30.30	75.42	66.11	50.02	41.20	4.67	6.31	8.94	17.74	29.29	5.48	7.12	9.74	18.26	29.80
39.40	91.12	77.78	61.22	49.95	5.62	8.08	11.89	23.64	39.61	6.43	8.89	12.69	24.16	40.12
48.50	106.82	89.45	72.22	58.70	6.57	9.85	14.84	29.54	49.93	7.38	10.66	15.64	30.06	50.44
57.70	122.62	101.12	83.22	67.45	7.52	11.62	17.79	35.44	60.25	8.33	12.43	18.59	35.96	60.76

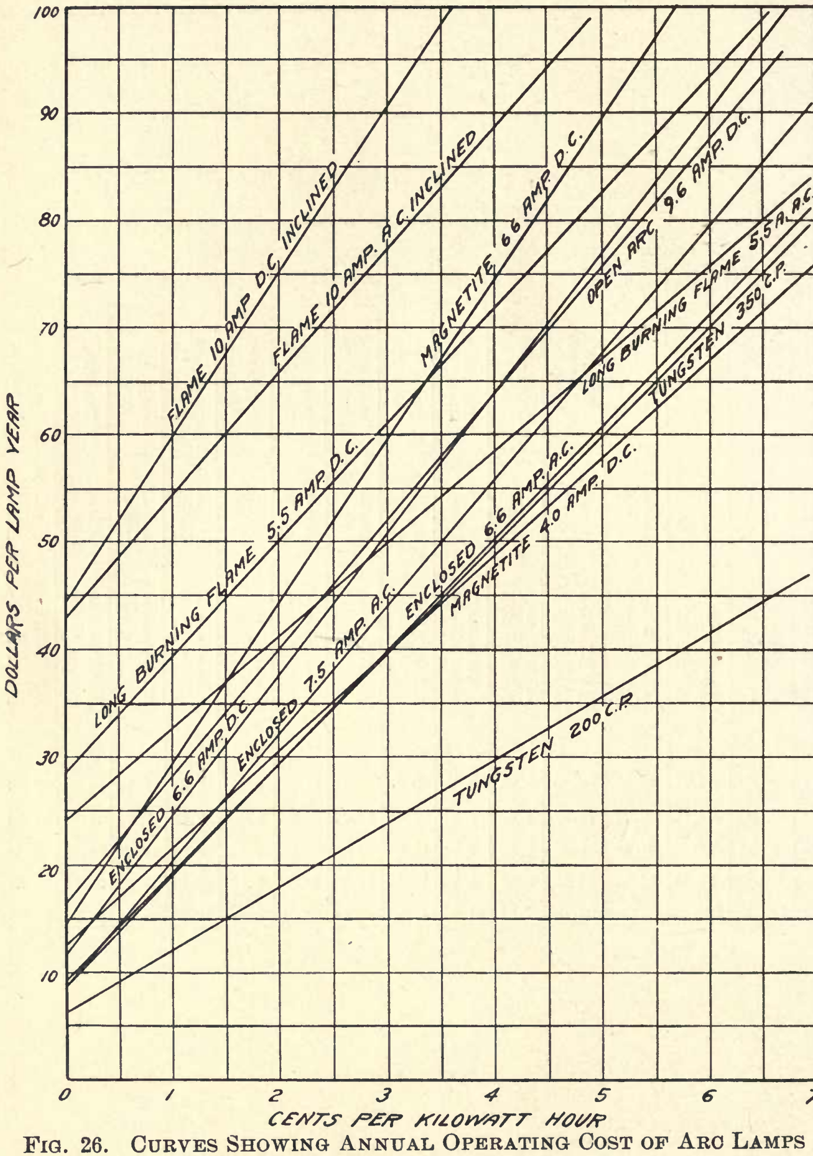

FIG. 26. CURVES SHOWING ANNUAL OPERATING COST OF ARC LAMPS ON 2500-HR. SCHEDULE

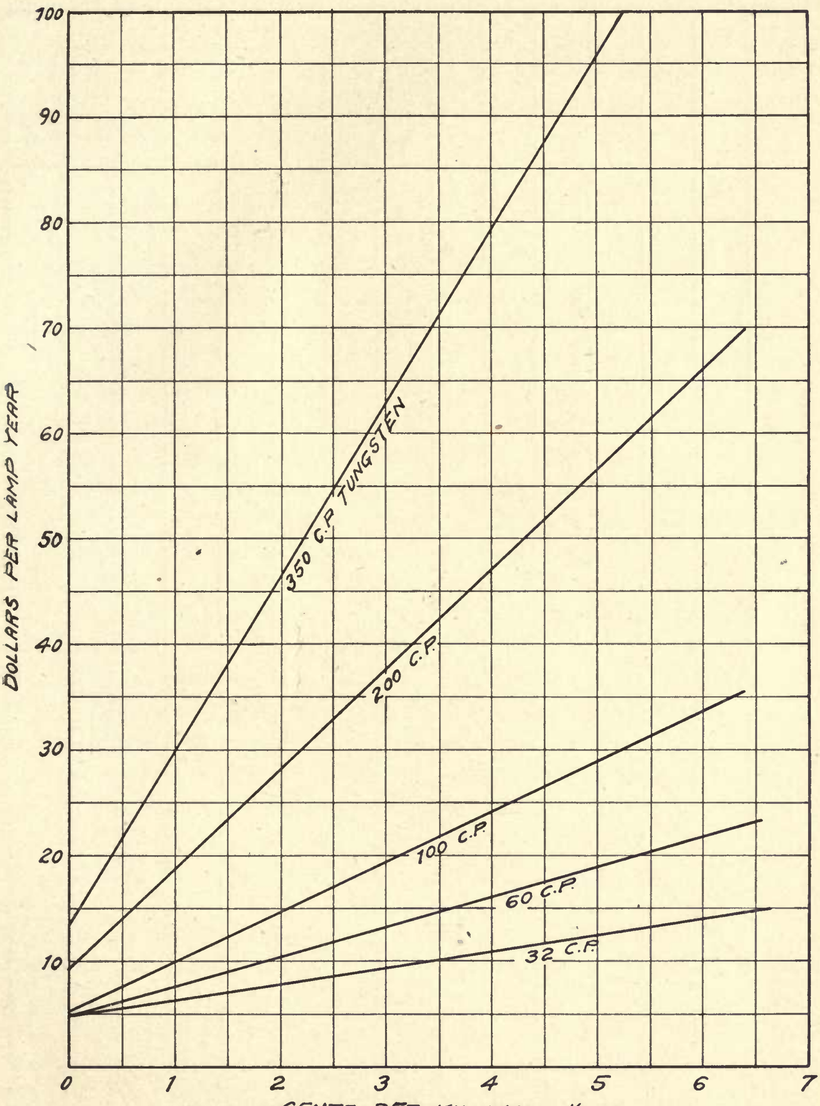

FIG. 27. CURVES SHOWING ANNUAL OPERATING COST OF TUNGSTEN LAMPS ON 4000-HR. SCHEDULE

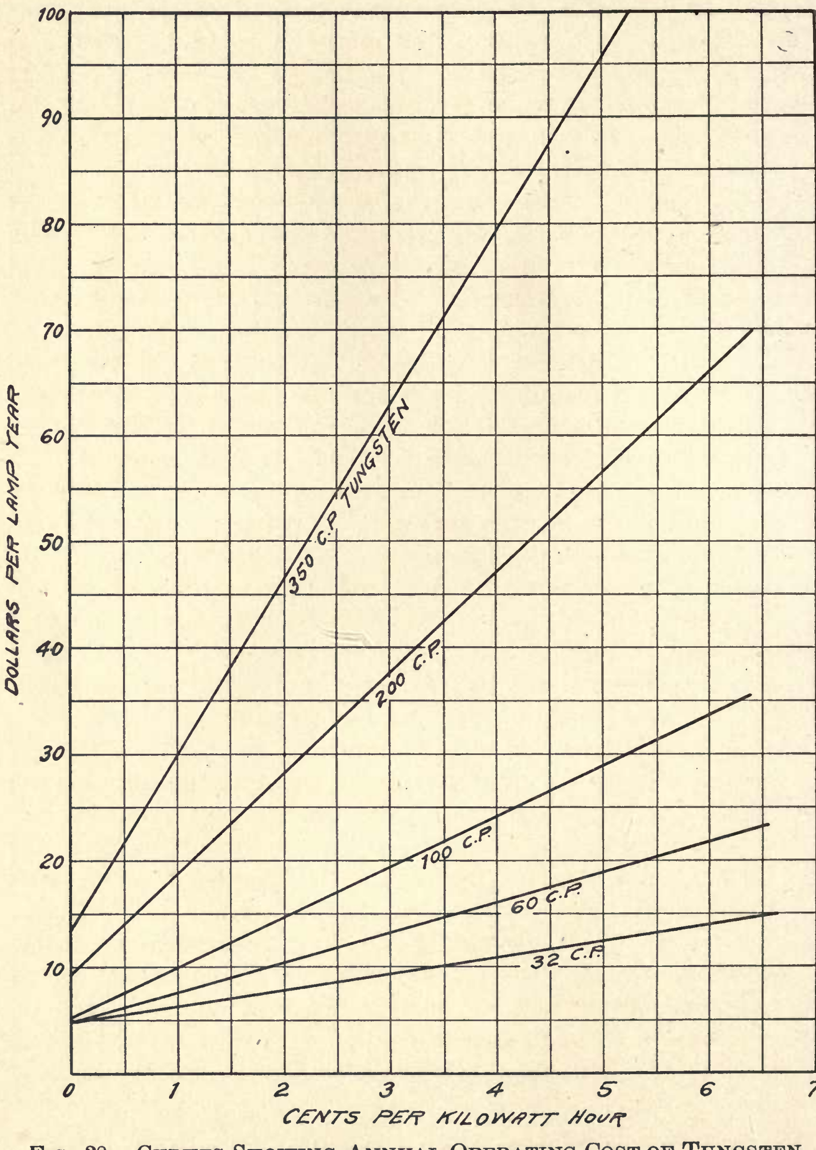

FIG. 28. CURVES SHOWING ANNUAL OPERATING COST OF TUNGSTEN LAMPS ON 2500-HR. SCHEDULE

item of labor and supplies is large for the open arc, and for short burning flame arcs. In fact, the maintenance charge on these lamps is nearly equal to the total operating charge on some of the other lamps. This is not offset by a proportionately greater amount of light. In the tungsten lamps, the energy charge is rather more important than in most of the arc lamps, but the fixed and maintenance charges are low on account of the long life of these lamps. Although the cost of each renewal is rather high, only very few renewals have to be made each year.

In the case of cities where a lighting system using series lights is already installed, the question arises as to the proper rate to be agreed upon in a new ordinance. This is usually computed on the basis of the lights at present in use, or these lights replaced by the same number of lamps of some different type. In fixing the rate for these new lights, Tables 17 and 18 or Fig. 22 to 28 will be of direct application, since the rate will be in proportion to the cost per lamp per year. A comparison of the lamps on the basis of street distribution will show whether the new lamp is equivalent to the old one in illuminating power. It will be seen that with four cent energy, a saving of $4 per lamp per year may be expected by replacing 6.6 amperes A. C. lamps with 4.0 ampere magnetites. At the same time, the street illumination is improved. For 100 lamps, this means a saving of $400 per year on the 4000 hour schedule. The 200 C. P. tungsten light would give as good satisfaction as the 6.6 amperes A. C., on account of its steady light, and at a saving of $3200 per year for the 100 lights.

It has been shown, from the comparison of Tables 17 and 18, that the high cost of maintenance for short burning lamps makes their yearly cost very high on any schedule or cost of energy, in comparison with the long burning lamps. This can be compensated for only by the use of fewer lamps. It will be seen, however, that for residence districts, the illumination is so low at the minimum point that none of the lamps can be spaced at a greater distance than 400 ft., or one block. Hence the comparison of arc lamps for this class of service must be made upon this spacing. The illumination on such streets can be improved only by using smaller units spaced closer together. This is the special field for the tungsten lamps. To show this more clearly, the following comparison has been made.

Problem.—To light a shaded residence street one mile long, 400 ft. blocks, energy being assumed at three cents per kilowatt hour and the 4000 hour schedule. Using only the lower cost

lamps, Table 19, page 59, has been computed. It is seen that a good minimum and low maximum illumination can be produced by using tungsten lamps. There will be required 14 lamps at 400 ft. or 27 lamps at 200 ft. or 53 lamps at 100 ft. This is assuming that poles are spaced conveniently for this arrangement. It will be seen that nearly as good illumination is produced by 60 C. P. tungstens, spaced 100 ft. apart, as by any of the arc lights, except the 6.6 amperes magnetite, and at a cost of only $713 per year, compared with $3220 for the 6.6 A. C. enclosed. Probably the 200 C. P. tungsten would be selected at 200 ft. spacing, costing $1020, since the street would appear much more brilliantly lighted than with the 60 C. P. Other comparisons will doubtless suggest themselves, depending upon local conditions.

VII. Summary and Conclusions

From Tables 1, 2 and 3, it is seen that for uniform distribution of illumination on a surface from single light sources, their illumination not overlapping to any extent requires very low values of intensity at angles near the vertical, and to as wide an angle as 60°, except where the lights are suspended high over the surface to be illuminated. A comparison of the curves in Fig. 3, 4 and 5 for arc lamps with these tables shows that none of these distribution curves can be expected to give uniform low illumination. Curves of the shape of those shown by B or C, Fig. 3, or A or C, Fig. 5, will give wider uniform distribution than the other curves shown. Curve A, Fig. 3, shows that a bright ring of light must be expected at a distance from the base of the lamp equal to the light with a dark circular area within, and a rather abrupt dark area without. For curves in Fig. 4, the lamps must be spaced a little farther apart than their height. A considerable amount of light between 60° and 90° is available for overlapping. Curves B and D, Fig. 5, and the curves on Fig. 6 show that these lamps must be used spaced rather close together. Inclined carbon flame lamps can be used successfully only for very bright illumination, on account of the intensity at the zero angle. For dim uniform illumination, the tungsten light is the proper one to chose, on account of the lower intensity available in the small units and its excellent distribution curve for this purpose. This point is very strikingly brought out by comparing the illumination curves in Fig. 22.

A lamp throwing a strong light at a wide angle must be surrounded by an opal globe in order to lower its intrinsic brilliancy. The lower the light is hung over the center of the street, the

TABLE 19

Annual Cost of Lighting One Mile of Street for .02-ft. Candle Horizontal Illumination

ITEMS	Illumination in Foot Candles						Annual Cost								For .02 ft. Candle Minimum					
	Spacing 400′		Spacing 200′		Spacing 100′		1 Lamp	Per Mile of Street 4000 Hr. Schedule			1 Lamp	Per Mile of Street 2500 Hr. Schedule			Distance Apart	Lights per Pole	Foot Candle		Cost	
	Max.	Min.	Max.	Min.	Max.	Min.		14 Lamps 400′	27 Lamps 200′	53 Lamps 100′		14 Lamps 400′	27 Lamps 200′	53 Lamps 100′			Max.	Min.	4000 Hour	2500 Hour
Enclosed D. C. 6.6 Ampere	.36	.003	.372	.023	—	—	79.80	1120	2150	4230	51.89	727	1400	2750	200	1	.372	.023	2150	1400
Enclosed A. C. 7.5 Ampere	.336	.0016	.34	.012	—	—	68.56	960	1820	3635	44.05	617	1190	2330	200	2	.68	.024	3640	2380
Enclosed A. C. 6.6 Ampere	.28	.0014	.28	.009	—	—	61.68	865	1660	3270	39.73	556	1083	2100	200	2	.56	.02	3300	2166
Magnetite D. C. 6.6 Ampere	.80	.009	.85	.069	—	—	91.12	1275	2460	4830	59.27	830	1600	3140	400	2	1.8	.018	2550	1660
Magnetite D. C. 4.0 Ampere	.56	.004	.564	.033	—	—	59.16	827	1595	3130	39.40	552	1065	2090	200	1	.564	.033	1595	1065
Flame D. C. 10.0 Ampere Inclined	3.81	.008	3.82	.07	—	—	140.28	2000	3850	7450	91.12	1275	2460	4830	400	2	7.62	.016	4000	2550
Flame D. C. 5.5 Ampere Long Burning	1.26	.012	1.27	.084	—	—	92.20	1290	2490	4880	61.22	857	1650	3240	400	2	2.52	.024	2580	1714
Tungsten 200 C. P. Center Suspension	.362	.003	.365	.023	.366	.068	37.11	520	1000	1968	23.64	331	638	1250	200	1	.365	.023	1000	638
Tungsten 350 C. P. Center Suspension	.37	.002	.37	.025	—	—	62.56	875	1690	3311	39.61	555	1070	2100	200	1	.37	.025	1690	1070
Tungsten 32 C. P. Side Suspension	—	—	.06	.002	.06	.01	9.48	133	256	503	6.43	90	174	341	100	2	.12	.02	1006	682
Tungsten 60 C. P. Side Suspension	—	—	.11	.003	.11	.021	13.44	188	363	713	8.89	126	243	477	100	1	.11	.021	713	477
Tungsten 100 C. P. Side Suspension	—	—	.181	.005	.183	.034	19.47	273	525	1032	12.69	178	342	673	100	1	.183	.034	1032	673
Tungsten 200 C. P. Side Suspension	.362	.003	.365	.023	.366	.068	37.71	528	1020	2000	24.16	338	652	1280	200	1	.365	.023	1020	652
Tungsten 350 C. P. Side Suspension	.575	.002	.6	.02	—	—	63.15	883	1700	3350	40.12	561	1080	2120	200	1	.6	.02	1700	1080

Height 25 ft. for Arcs and 350 C. P. Tungstens.
Height 20 ft. for all others.

more is this important. For very bright lights like the flame arcs, this must also be observed, even when the lights are hung high as they are still in the line of vision and effective at a greater distance. The sentiment of the general public is beginning to demand this consideration more and more each year.

VIII. APPENDIX

Definitions

Candle-Lumen.—The total flux of light from a source is equal to its mean spherical intensity multiplied by 4π (12.57). The unit of flux is called *lumen.* A *lumen* is the $\frac{1}{4\pi}$ th (0.0796) part of the total flux of light emitted by a source having a mean spherical itensity of one candle-power. A *hefner-lumen* is a 0.90 lumen.

Candle-power.—The luminous intensity of sources of light is expressed in *candle-power.* The unit of candle-power should be derived from the standards maintained by the National Bureau of Standards at Washington, D. C. The *hefner* is 0.90 of this unit. In practical measurements, seasoned and carefully standardized incandescent lamps are more reliable and accurate than the primary standard.

Efficiency of Electric Lamps.—The efficiency of electric lamps is properly stated in mean spherical candle-power per watt, and preferably in lumens per watt at the lamp terminals.

Electrode.—Either of the terminals of an arc lamp between which the arc is formed. The electrodes are sometimes called the carbons.

Foot-candle.—Illumination is expressed in foot-candles. A foot-candle is the normal illumination produced by one unit of candle-power at a distance of one foot.

Mean Horizontal Candle-power.—The average intensity of light in a horizontal plane passing through the center of light source.

Mean Spherical Candle-power.—The average candle-power of a source taken over the surface of a sphere having its center at the source of light. It is numerically equal to the total light emitted divided by 4π (12.57).

Mean Hemispherical Candle power.—The average candle-power in a hemisphere having the center of its plane surface at the center of the light source. Usually the lower hemisphere is chosen.

Note.—The hefner is a unit used mostly in Germany. It is smaller than the candle-power. 1 hefner = .9 candle power.

Moonlight Schedule.—A schedule of burning hours for lamps, the lamps burning only when the moon does not shine; in this bulletin, 2500 hours burning per year.

Watts per Candle-power.—The specific consumption of an electric lamp is its watts consumption per mean spherical candle-power. "Watts per candle" is a term used commercially in connection with incandescent lamps, and denotes watts per mean horizontal candle-power.

Load Factor.—Load factor is the ratio between the average load and the maximum load for the given day.

Reading Distance.—Where standard photometric measurements are impracticable, approximate measurements of illuminants used as street lamps may be made by comparing their "reading distances", i. e., by determining alternately the distances at which an ordinary size of reading print can just be read, by the same person or persons, where all other light is screened. The angle below the horizontal at which the measurement is made should be specified when it exceeds 15°.

PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

ALL BULLETINS, THE TITLES OF WHICH ARE NOT STARRED, WILL BE SENT FREE UPON APPLICATION.

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. *None available.*

Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available.*

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. *None available.*

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906. *None available.*

Circular No. 3. Fuel Tests with Illinois Coal. (Compiled from tests made by the Technologic Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907,) by L. P. Breckenridge and Paul Diserens. 1909. *Thirty cents.*

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L P. Breckenridge. 1906. *None available.*

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906. *Forty-five cents.*

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman. 1906. *Fifteen cents.*

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906. *Thirty-five cents.*

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr and Henry B. Dirks. 1906. *Thirty-five cents.*

Bulletin No. 8. Tests of Concrete: I. Shear; II. Bond, by Arthur N. Talbot. 1906 *None available.*

Bulletin No. 9. An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906. *None available.*

Bulletin No. 10. Tests of Concrete and Reinforced Concrete Columns, Series of 1906, by Arthur N Talbot. 1907. *None available.*

Bulletin No. 11. The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907. *Fifteen cents.*

Bulletin No. 12. Tests of Reinforced Concrete T-beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 13. An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1907. *Fifty cents.*

Bulletin No 14. Tests of Reinforced Concrete Beams, Series of 1906, by Arthur N. Talbot 1907. *None available.*

Bulletin No. 15. How to Burn Illinois Coal without Smoke, by L. P. Breckenridge. 1908 *Twenty-five cents.*

Bulletin No. 16. A Study of Roof Trusses, by N. Clifford Ricker. 1908. *Fifteen cents.*

Bulletin No. 17 The Weathering of Coal, by S. W. Parr, N. D. Hamilton, and W. F. Wheeler. 1908. *Twenty cents.*

Bulletin No. 18. The Strength of Chain Links, by G. A. Goodenough and L. E. Moore. 1908. *Forty cents.*

Bulletin No. 19. Comparative Tests of Carbon, Metallized Carbon and Tantalum Filament Lamps, by T. H. Amrine. 1908 *Twenty-five cents.*

Bulletin No. 20. Tests of Concrete and Reinforced Concrete Columns, Series of 1907, by Arthur N. Talbot. 1908. *None available.*

Bulletin No. 21. Tests of a Liquid Air Plant, by C. S. Hudson and C. M. Garland. 1908. *Fifteen cents.*

Bulletin No. 22. Tests of Cast-Iron and Reinforced Concrete Culvert Pipe, by Arthur N. Talbot. 1908. *Thirty-five cents.*

Bulletin No. 23. Voids, Settlement and Weight of Crushed Stone, by Ira O. Baker. 1908. *Fifteen cents.*

Bulletin No 24. The Modification of Illinois Coal by Low Temperature Distillation, by S. W. Parr and C. K. Francis. 1908. *Thirty cents.*

Bulletin No 25. Lighting Country Homes by Private Electric Plants, by T. H. Amrine. 1908. *Twenty cents.*

Bulletin No. 26. High Steam-Pressures in Locomotive Service. A Review of a Report to the Carnegie Institution of Washington, by W. F. M. Goss. 1908. *Twenty-five cents.*

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*Out of print; price attached.

PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION—(*Continued*)

Bulletin No. 27. Tests of Brick Columns and Terra Cotta Block Columns, by Arthur N. Talbot and Duff A. Abrams. 1909. *Thirty cents.*

Bulletin No. 28. A Test of Three Large Reinforced Concrete Beams, by Arthur N. Talbot. 1909. *Fifteen cents.*

Bulletin No. 29. Tests of Reinforced Concrete Beams: Resistance to Web Stresses, Series of 1907 and 1908, by Arthur N. Talbot. 1909. *Forty-five cents.*

Bulletin No. 30. On the Rate of Formation of Carbon Monoxide in Gas Producers, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1909. *Twenty-five cents.*

Bulletin No. 31. Fuel Tests with House-heating Boilers, by J. M. Snodgrass. 1909. *Fifty-five cents.*

Bulletin No. 32. The Occluded Gases in Coal, by S. W. Parr and Perry Barker. 1909. *Fifteen cents.*

Bulletin No. 33. Tests of Tungsten Lamps, by T. H. Amrine and A. Guell. 1909. *Twenty cents.*

Bulletin No. 34. Tests of Two Types of Tile Roof Furnaces under a Water-tube Boiler by J. M. Snodgrass. 1909. *Fifteen cents.*

**Bulletin No. 35.* A Study of Base and Bearing Plates for Columns and Beams, by N. Clifford Ricker. 1909. *Twenty cents.*

Bulletin No. 36. The Thermal Conductivity of Fire-Clay at High Temperatures, by J. K. Clement and W. L. Egy. 1909. *Twenty cents.*

**Bulletin No. 37.* Unit Coal and the Composition of Coal Ash, by S. W. Parr and W. F. Wheeler. 1909. *Thirty-five cents.*

Bulletin No. 38. The Weathering of Coal, by S. W. Parr and W. F. Wheeler. 1909. *Twenty-five cents.*

Bulletin No. 39. Tests of Washed Grades of Illinois Coal, by C. S. McGovney. 1909. *Seventy-five cents.*

Bulletin No. 40. A Study in Heat Transmission, by J. K. Clement and C. M. Garland. 1910. *Ten cents.*

Bulletin No. 41. Tests of Timber Beams, by Arthur N. Talbot. 1910. *Twenty cents.*

Bulletin No. 42. The Effect of Keyways on the Strength of Shafts, by Herbert F. Moore. 1910. *Ten cents.*

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Bulletin No. 46. The Spontaneous Combustion of Coal, by S. W. Parr and F. W. Kressmann. 1911. *Forty-five cents.*

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Bulletin No. 50. Tests of a Suction Gas Producer, by C. M. Garland and A. P. Kratz. 1911. *Fifty cents.*

Bulletin No. 51. Street Lighting, by J. M. Bryant and H. G. Hake. 1911. *Thirty-five cents.*

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ANNOUNCEMENT CONCERNING A MODIFICATION IN THE RULES GOVERNING THE DISTRIBUTION OF BULLETINS

The Board of Trustees of the University of Illinois voted, December 3, 1910, that a price should be affixed to certain University publications, among them being the Bulletin of the Engineering Experiment Station.

This action, so far as it concerns the bulletins of the Engineering Experiment Station, has for its purpose a threefold object:

(1) To provide a greater degree of control in the distribution of bulletins.

(2) To make possible the establishment and maintenance of a trade circulation through the regular publishing houses.

(3) To regulate the distribution of the reserve or "out-of-print" supply.

IT IS NOT INTENDED THAT THIS ACTION SHALL OPERATE IN ANY WAY TO ABRIDGE THE PRIVILEGES OF THOSE WHO HAVE HITHERTO RECEIVED THE BULLETINS OF THE STATION GRATUITOUSLY, OR TO PREVENT REASONABLE EXTENSIONS OF THE EXISTING MAILING LISTS.

Practice under the new procedure will be as follows:

(1) All bulletins, hereafter issued, will have a price printed upon the cover, together with the name of the London sales agent.

(2) EACH BULLETIN, HOWEVER, WILL STILL BE SUBJECT TO A FREE INITIAL DISTRIBUTION, AS HERETOFORE, ON THE BASIS OF EXISTING MAILING LISTS.

It will also be placed on sale with authorized agencies, both in this country and abroad.

(3) THERE WILL BE A LIMITED NUMBER OF COPIES AVAILABLE FOR FREE DISTRIBUTION, UPON REQUEST, AFTER THE INITIAL DISTRIBUTION.

(4) As the supply of each bulletin approaches exhaustion, it will be placed upon a reserve or "out-of-print" list. THE EFFECT OF THIS ACTION WILL BE TO WITHDRAW SUCH BULLETINS FROM FREE DISTRIBUTION. Bulletins withdrawn from free distribution will be available to any applicant upon payment of the assigned price.

(5) A discount from the published price will be allowed to news agents regularly handling the bulletins.

W. F. M. GOSS
Director.